HABITAT ASSOCIATIONS, DISTRIBUTION, AND ABUNDANCE OF SMITH'S LONGSPUR (*CALCARIUS PICTUS*), AN UNCOMMON SPECIES OF CONCERN IN THE BROOKS RANGE, ALASKA.

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ABSTRACT

Smith's Longspur (*Calcarius pictus*) is a species of conservation concern in the U.S. and Canada, yet few studies have been conducted on their breeding grounds in the Arctic, which are expected to undergo dramatic changes due to climate change. For effective conservation, we need information on breeding distribution and abundance; thus I conducted surveys for Smith's Longspur and habitat characteristics across a broad geographic range that included twelve sites within Alaska's Brooks Range, June 2003-2009. My main objectives were to (1) locate breeding populations (2) describe habitats at local and broader geographic scales, (3) develop a predictive distribution map based on habitat characteristics, and (4) estimate densities and abundance of Smith's Longspurs. Smith's Longspurs were detected at seven of twelve sites and were associated with mixed sedge and shrub habitats with high cover of moss and sedges. Across the Brooks Range, I predicted patchy occurrence in valleys and foothills in the north- and south-eastern mountains and in upland plateaus in the western mountains. Density estimates varied, ranging from 0 - 0.39 males/ha due to their patchy distribution within and among sites. I estimated abundance as ~30,000 males in the Brooks Range. My data provides a baseline for future monitoring of this little-known species.

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GENERAL INTRODUCTION

For many landbirds, information about habitat associations, distribution, and abundance is inadequate for conservation planning and wildlife management. In the Arctic, threats from climate change are expected to be dramatic and accelerated (Arctic Climate Impact Assessment 2004), adding urgency to our need for this information, especially for species already thought vulnerable to extinction or population decline (North American Bird Conservation Initiative 2010). To aid conservation of a species for which little is known, I studied Smith's Longspur (*Calcarius pictus*), a migrant landbird that breeds along the tundra-forest transition zone in arctic and sub-arctic North America (Briskie 2009). Smith's Longspur is identified as a species of conservation concern by Boreal Partners in Flight (Boreal Partners in Flight 1999), the U.S. Fish and Wildlife Service (US Fish & Wildlife Service 2008), Canadian Wildlife Service (Dunn et al. 1999), and Alaska Department of Fish and Game (Alaska Department of Fish and Game 2006).

The species is considered susceptible to population decline due to what is believed to be a small total population size, coupled with a geographically small wintering range. Although the total population size is unknown, a population estimate of <75,000 birds was extrapolated by Briskie (2009) using the density of breeding birds in the easternmost part of their breeding range, near Churchill, Manitoba in Canada and applying it to the area of their estimated range. Based on the few published accounts on Smith's Longspur, it is believed they are associated with tundra habitats at the northern edge of the tundra-forest transition zone from Hudson Bay to the Central Brooks Range in northern Alaska (Sage 1976, Sinclair et al. 2003, Briskie 2009); they are also occasionally found above treeline in the mountains of central and southeastern Alaska into Canada (Weedon 1960, Sage 1976). Most of what is known of Smith's Longspur breeding ecology is from work conducted in the eastern part of their range in Churchill (Jehl 1968, Briskie 1992, Briskie 1993, Briskie 1999). Knowledge of habitat associations, distribution, or abundance in other parts of their breeding range is limited to anecdotal accounts documenting occurrence during the breeding season (Sage 1976) and citizen science sources such as eBird (http://ebird.org/content/ebird/about/). Because information on the species across it's breeding range is sparse, understanding distribution and abundance is a critical first step in developing an informed assessment

and conservation plan for this species (Boreal Partners in Flight 1999, Alaska Department of Fish and Game 2006).

To help fill in the gaps in information about Smith's Longspurs, particularly in the western portion of their range, I conducted research on the distribution and abundance of Smith's Longspur across a broad geographic range within the Brooks Range in northern Alaska. Across the state, anecdotal accounts suggest that Smith's Longspur are generally uncommon, but locally abundant in some areas, particularly in the broad tundra valleys and northern foothills of the eastern Brooks Range (Kessel and Schaller 1960, Sage 1976, Kessel and Gibson 1978, Gotthardt and Jansen 2004). Current broad-scale monitoring programs in northern Alaska, such as the Breeding Bird Survey (BBS) or Alaska Landbird Monitoring Survey (ALMS), insufficiently assess Smith's Longspur populations (Boreal Partners in Flight 1999, Rich et al. 2004). This is due both to the rarity of the species and the limited coverage of bird surveys in northern Alaska. I conducted bird and habitat surveys at 12 sites across the Brooks Range to (1) locate breeding areas, (2) describe habitat associations, (3) create a predictive distribution map based on habitat characteristics, and 4) estimate densities and abundance of Smith's Longspurs.

In Chapter 1, I described local and landscape scale habitat associations and produced a map to identify areas of high and low predicted occurrence. In Chapter 2, I calculated the first density estimates for the species in the western part of its breeding range. Then I combined the density estimates with the predicted distribution model from Chapter 1 to generate a population estimate for the Brooks Range. I also evaluated the effectiveness of two common survey methods and made recommendations to further improve abundance surveys for the species. With reliable distribution and quantified abundance information for the Brooks Range, land managers can then move forward with developing conservation plans and monitoring programs for Smith's Longspurs.

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CHAPTER 1

HABITAT ASSOCIATIONS AND PREDICTED DISTRIBUTION OF BREEDING SMITH'S LONGSPUR IN ALASKA'S NORTHERNMOST MOUNTAINS, THE BROOKS RANGE.[1]

ABSTRACT

Smith's Longspur (*Calcarius pictus*) is a species of conservation concern, yet little is known about its breeding distribution or associated habitats. This information is increasingly important because arctic habitats are expected to be especially vulnerable to the effects of climate change. To develop effective conservation measures, we need an understanding of the species' distribution across the landscape and its habitat requirements. We used bird and habitat data from point-count surveys conducted at 12 sites across the Brooks Range in 2003-2009 to identify breeding areas, describe local habitat associations, and create a predictive model of their distribution. Smith's Longspurs were observed at seven sites, where they were associated with a variety of sedge-shrub habitats composed primarily of moss, sedges/tussocks, and dwarf shrubs; erect shrubs were common but sparse. Non-metric multidimensional scaling ordination of ground cover depicted positive associations of Smith's Longspur presence with sedges and moss and negative association with high cover of shrubs. To model predicted distribution, we used boosted regression trees to relate landscape variables to occurrence patterns of Smith's Longspurs. Our model predicted that Smith's Longspurs occur in valleys and foothills in the north- and south-eastern mountains and in upland plateaus in the western mountains, farther west than currently documented. With climate change, shrubs are expected to grow larger and denser, while soil moisture and moss cover decrease. These changes may reduce Smith's Longspur habitat quality and limit distribution in the Brooks Range to poorly drained lowlands and alpine plateaus where sedge-shrub tundra is likely to persist. Conversely, northward advance of shrubs into sedge tundra may create suitable habitat, thus supporting a northward distribution shift. More research is needed on breeding site fidelity and dispersal to understand the potential impact from climate change.

[1]Wild, T., S. Kendall, A. Powell, and N. Guldager. Habitat associations and predicted distribution of breeding Smith's Longspur in Alaska's northernmost mountains, the Brooks Range. Prepared for submission to *Avian Conservation and Ecology*.

INTRODUCTION

Climatically driven changes in vegetation are projected to alter avian habitats and distributions worldwide (Crick 2004). Arctic birds are particularly vulnerable because ecosystem and habitat changes are expected to be accelerated and dramatic at northern latitudes (Arctic Climate Impact Assessment 2004; North American Bird Conservation Initiative 2010). Expansion of shrubs and trees in the Arctic could alter the breeding habitat of 15% of the world's bird species (Wormworth and Mallon 2006). For arctic species that are already of conservation concern, the potential effects of climate change may be especially important (North American Bird Conservation Initiative 2010).

Smith's Longspur (*Calcarius pictus*) is a species of conservation concern with a breeding range restricted to arctic and subarctic regions of western and central North America. Its status as a species of conservation concern is in part because little is known about its breeding habitats or distribution (Briskie 2009). In the spring, Smith's Longspurs migrate north from the southern Great Plains to breed in sedge tundra at the northern edge of the tundra-forest transition zone as far east as the southern shores of Hudson Bay in Ontario, Canada and as far west as the central Brooks Range in northern Alaska, United States. Small, isolated pockets have also been documented above treeline in alpine tundra meadows in southeast Alaska and northern British Columbia, Canada (Briskie 2009).

Due to the remoteness of Smith's Longspurs' breeding areas, current understanding of their distribution, habitat associations, and population status is limited to anecdotal accounts and local studies at a few accessible locations. Previous studies of breeding Smith's Longspur were focused primarily on behavior and reproductive physiology (Meddle et al. 2003, Briskie 2009) and much of our knowledge regarding breeding habitat comes from studies in eastern Canada (Jehl 1968). The few accounts of Smith's Longspurs in Alaska documented only occurrence and general habitat associations within small areas; in general they were found breeding at the northern edge of the forest-tundra transition zone in moist, hummocky tundra and wet sedge habitats in the valleys and foothills of the Brooks Range and in high elevation valleys in the Wrangell-St. Elias Mountains (Hines 1963, Sage 1976, Kessel and Gibson 1978). The expanse of

various tundra habitats in northern Alaska likely supports the core of Smith's Longspur populations in Alaska. However, these tundra habitats may be altered by shrub and tree expansion as climate warms in this region. We cannot assess potential impacts from climate change on Smith's Longspurs without baseline knowledge of current distribution or habitat associations.

The majority of land in the Brooks Range is managed by the National Park Service and US Fish and Wildlife Service. To support conservation planning by these agencies, we documented Smith's Longspur habitat associations and distribution across the Brooks Range of northern Alaska. Our specific goals were to (1) survey selected sites across the Brooks Range to discover where Smith's Longspurs breed, (2) describe the local habitats and vegetative ground cover associated with breeding areas, and (3) use species occurrence data from surveys and landscape variables to predict where other suitable breeding areas may be found across the Brooks Range ecoregion. This is the first study to document occurrence of breeding Smith's Longspurs across a large geographic range, and to examine habitat associations at two different scales. The predictive model and analysis of habitat associations can be used to generate hypotheses about conservation challenges this species may face in the future, as well as refine future survey efforts for Smith's Longspur's in northern Alaska.

METHODS

Study area

We conducted our study in the Brooks Range, Alaska (Fig. 1.1), where Smith's Longspurs were known to breed in several large river valleys (Boreal Partners in Flight 1999). The Brooks Range ecoregion (15.6 million ha; Nowacki et al. 2001) encompasses the northernmost mountain range in North America and is almost entirely above the Arctic Circle. It extends westward for 1200 km from the Yukon Territory, Canada to within 100 km of Chukchi Sea in western Alaska. Elevations were 500-2600 m. Our surveys fell within a geographic area between 66°46' and 69°40' north latitudes (258-km extent), and 141°1' and 156°23' west longitudes (639-km extent).

The rugged, barren mountains of the Brooks Range separate the interior boreal forests in the south from the treeless arctic tundra to the north. The Brooks Range is remote and mostly undeveloped with only a few small communities and settlements scattered across the range. The region includes nearly 8.5 million ha of designated Wilderness managed by the US Fish and Wildlife Service and National Park Service, thereby limiting travel to and within sites. We accessed remote study sites by fixed-wing aircraft and traveled between routes using inflatable canoes and on foot; one site was accessible from the Dalton Highway.

Data collection

We surveyed 12 sites across the Brooks Range during two survey efforts (Park and focused surveys) in June 2003-2009 (Fig. 1.1). We conducted Park surveys in June 2003-2005 in Gates of the Arctic National Park and Preserve to study the distribution, diversity, abundance, and habitat of all bird species within six major river corridors (Guldager 2004). Listed from west to east with coordinates based on the North American Datum 1983, the six Park study sites included Noatak (N67.59614, W-155.23120), Alatna (N67.90167, W-155.08356), Killik (N68.15116, W-154.16810), John (N67.61880, W-152.27310), North Fork Koyukuk (N67.38969, W-150.76447), and Itkillik (N68.25089, W-149.99295). The objective of focused surveys, conducted in 2006-2009, was to survey for Smith's Longspur in areas of historical observations or regions thought to have suitable habitat. Focused surveys, conducted in 2006-2009, were located east of the Dalton Highway within the Arctic National Wildlife Refuge and included Atigun Gorge (N68.467598, W-149.293126), Canning (N69.34383, W-146.09614), Sunset Pass (N69.65898, W-144.72961), Sheenjek (N68.71628, W-143.82663), Coleen (N68.62161, W-142.45140), and Firth (N68.66156, W-141.09158).

Although the objectives of the two efforts were different, survey methods were identical for all 12 sites sampled. Study site boundaries were delineated for the 12 sites in ArcMap (ESRI 2008). The size and shape of the study sites varied due to differences among the valleys sampled and access limitations. Six to 15 survey routes, each made with 10-12 points, were selected at each study site using a sequential random sampling design. Survey points were sequentially selected from a point array with 500 m spacing,

based on a random starting point and a pre-determined number of points between each route. The spacing between routes and the number of routes varied for each study site based on the number of points in each site and the number of days available to survey. With this design, sampling effort was constant within a study site, but varied among sites. During field surveys, inaccessible points such as those on cliffs or in rivers were dropped and replaced with the next sequential point(s). On focused surveys, we similarly dropped points with >50% forest cover to avoid surveying where the species is not known to occur. As a result, sampling effort differed between Park and focused surveys because Park surveys included many forested points.

Smith's Longspur presence/absence

At each survey point, we performed variable circular-plot point counts and recorded all bird species detected by sight and sound (Reynolds et al. 1980). We conducted 10-min point counts between 02:30 and 09:00 under conditions of good visibility, little or no precipitation, and light winds, in accordance with ALMS protocols (Handel and Cady 2004). Points where we detected the species were classified as "presence" points; all other points were classified as "absence" points. All data were collected in accordance with federal animal care and research permits (University of Alaska, Fairbanks IACUC #07-19).

Local habitat

We classified habitat and recorded ground cover characteristics on 100-m radius plots centered on bird survey points. Following the Alaska Vegetation Classification System (Viereck and Station 1992), we classified forest, scrub and herbaceous (hereafter "tundra") habitats based on the structure of dominant over-story vegetation. Habitats with tree canopy cover >25% were classified as forest. Woodland habitats had 10–24% tree canopy cover. Shrub habitats, containing <10% tree cover and dominated by shrubs >20-cm tall, were defined by an open (25–74%) or closed (>75%) shrub canopy. Dwarf shrub habitats, dominated by shrubs <20-cm tall, were further classified according to the dominant dwarf shrubs: dryas, willow dwarf, and ericaceous. Tundra habitats could have up to 25% shrub cover and included graminoid (hereafter "sedge"), forb, byroid, and aquatic habitat classes. We further defined sedge tundra classes by

moisture levels: wet tundra had standing water, and mesic (hereafter moist) tundra was wet but rarely with standing water. Following ALMS protocols, we only classified habitats with an estimated patch size of ≥400 m^2 that was partially or entirely within the 100-m radius plots (Handel and Cady 2004). When multiple habitat types were identified within a plot, we visually estimated the proportional cover (%) of each class within the plot, with no overlap among classes.

To record the composition of ground cover on local habitat plots, we visually estimated percent cover for different trees, shrubs, forbs, sedges, moss, lichens, water, and bare ground. We also estimated average height for willow (*Salix* spp.) and birch (B*etula* spp.) shrubs >20 cm. Only plants with ≥5% ground cover within the plot were recorded. For sedges, we distinguished between tussock and non-tussock growth forms; tussocks were defined as a clump of grass or sedge with ≥15-cm diameter base and ≥7-cm height. The composition of ground cover was recorded at the species or genus level, but species present in <5% of plots were grouped into more general ground cover categories for analysis.

To focus on potentially suitable habitat and account for differences in study design, forested plots from Park surveys were not included in our habitat association summaries or analyses; only plots with ≤50% forest were used (present, n = 182; absent, n = 580). Local habitat data from one site were not available for analysis, resulting in a smaller dataset than was used for distribution modeling. To compare habitats on presence and absence plots, we calculated the mean cover ± SD of habitat types and ground cover components. We also calculated the relative frequency of occurrence of habitat types and ground cover components as the proportion of the plots where the habitat type or component was found relative to the total number of presence or absence plots. We examined patterns of ground cover structure by calculating the frequency of ground cover structural categories: trees, shrubs, dwarf shrubs, and forbs.

Landscape data

Additional landscape variables were included to describe the points using available spatial data using ArcMap 9.3 (ESRI 2008). We generated seven landscape variables

for use in analyses: ecotype, surface geology, distance to coast, distance to river, elevation, slope, and aspect.

Ecotype included 36 ecosystem classes from Ecosystems of Northern Alaska (Jorgenson and Heiner 2003). This predictive ecosystem model classified 30-m^2 raster cells based on vegetation, bedrock geology, topography, and physiognomy (alpine, upland, lowland, riverine, and coastal). Unfortunately, the spatial extent of this ecotype data did not cover the southeastern edge of our study area. Despite the lack of complete coverage, we used ecotype because it provided greater discrimination among tundra and shrub communities than other available vegetation datasets.

The surface geology variable included classes differentiating major geologic deposits (alluvial, fluvial, moraine, and drift) and their sources (coastal, glacial, and mountain). These data were derived from a digital version of the USGS surface geology map of Alaska (Karlstrom et al. 1964) at a scale of 1:1,584,000.

Topographic variables included elevation, slope, aspect, distance to river, and distance to coastline. Elevation, slope, and aspect were derived from the 60-m^2 raster USGS National Elevation Dataset (National Park Service 1999). We used the ESRI Digital Chart of the World (ESRI 1993) at 1:1,000,000 scale to calculate distances to ocean coast and rivers.

We extracted values for landscape data for each presence and absence point. For categorical variables, ecotype, and surface geology, we calculated the frequency of occurrence of classes and for continuous, topographical variables; we calculated means ± SD at presence and absence points.

Analyses

Local habitat associations

We used non-metric multidimensional scaling ordination (NMS; Kruskal 1964) to visually depict similarities and differences between ground cover at presence and absence points. This distance-based ordination method is well suited for exploring habitat

relationships because it assumes no underlying distribution of the data and allows for correlated variables commonly found in community data (McCune and Grace 2002). For this reason, NMS is a useful tool for assessing bird-habitat relationships (Lent and Capen 1995, Reinkensmeyer et al. 2007, Jobin and Falardeau 2010).

NMS calculated dissimilarity distance values for each of the survey points and arranged the points within a predetermined number of dimensions to fit with the ranked dissimilarity. The optimum solution was sought through an iterative process to maximize fit while maintaining the interpretability of the data by obtaining the fewest dimensions. After the ordination was made, we overlaid Smith's Longspur occurrence information (presence/absence and count) and the five continuous landscape variables (elevation, slope, aspect, distance to coast, and distance to river) to aid interpretation of the ordination and to identify the strongest associations between occurrence and habitat characteristics.

To build the ordination, we used PC-ORD (version 5.0), with a random starting configuration in the autopilot mode to test ordinations with up to four axes (McCune and Mefford 1999). We selected Sørensen distance, most often used with community data, to calculate dissimilarity values (McCune and Grace 2002). The remaining mis-match between ranked distance order and distance between points in the ordination space is reported as stress, and reflects the poorness-of-fit of the ordination. Stress values >30 indicate that the ordination is no different than what was observed at random and should not be interpreted (McCune and Grace 2002); values of 10–20 are typical for ecological data and considered acceptable. Fifty Monte Carlo simulations were run to determine the probability that our final stress value could have been achieved by chance (McCune and Grace 2002). The coefficient of determination, R^2, was calculated for each axis to reflect the variability explained by each axis. Pearson's correlation coefficients (*r*) were used to characterize the relationship between ordination axes and Smith's Longspur occurrence, ground cover components, and landscape variables. We present unsquared *r*-values to reflect strength as well as direction (+/-) of correlations, and visually depict strength and direction of the strongest correlations within the multidimensional space with vectors.

Distribution modeling

With little prior knowledge about Smith's Longspur habitat associations and distribution, we used survey results and landscape data to develop an exploratory species distribution model to predict occurrence using gradient-boosted regression trees (BRT). BRT has been used to model ecological relationships (Leathwick et al. 2006, Tanneberger et al. 2010) and is a top performer among techniques for predicting species distributions (Elith et al. 2006, Heikkinen et al. 2012, Oppel et al. 2012). We used BRT to predict Smith's Longspur occurrence for the Alaska portion of the Brooks Range ecoregion, expanded by a 10-km buffer (15.5 million ha). Within the ecoregion, we assumed sites would have similar biological communities, climate, and geographic characteristics and therefore distribution could be predicted using occurrence and landscape associations from select sites.

Because our study sites were primarily in river valleys, many common and prevalent landscapes were not surveyed, such as mountain peaks and ridges, talus hillsides, and high glacial basins and passes. Prediction beyond the valleys we studied was an extrapolation beyond the inference space of our sampling design because study sites were selected non-randomly to survey large river valleys (Park surveys) and to increase our chances of finding the uncommon Smith's Longspur (focused surveys). To reduce the effect of the sampling bias introduced to our distribution model and to sample other habitats within the region, we randomly created an additional 1000 background points within the ecoregion prediction area using Hawth's Tools in ArcMap (Beyer 2008). Background points were treated as absence points and were similar to pseudo-absence points that are commonly used in predictive species distribution models (Elith and Leathwick 2009).

Prior to building the species distribution model, we randomly withheld 30% of the presence points and 30% of the absence points to use as an evaluation dataset. To build the model, we used the remaining Smith's Longspur survey data and the background points along with seven landscape variables. To account for unequal sample sizes of presence (n = 173) and absence points (n = 641 survey + 1000

background), we balanced the weights of these occurrence classes for BRT analysis (Barbet-Massin et al. 2009). We used a maximum of six nodes per tree to allow for interactions between variables. To achieve good model fit without overfitting, the final number of trees was determined internally by optimizing lift using ten-fold cross-validation. To interpret the BRT results, landscape variables important to the model were ranked according to their relative contribution to variation in the model and partial dependence plots were created to view the relationship between individual variables and predicted occurrence: positive scores indicate support for presence, negative scores indicate support for absence (Elith et al. 2008).

To produce a predicted distribution map from the BRT distribution model, we created a square grid of points and extracted landscape variables for each point in the grid. This grid, called the predict-to grid, covered the ecoregion prediction area with 1-km spacing between points. We applied the model to the predict-to grid and used the BRT model to calculate an occurrence score based on the landscape variables for each point. Using GIS, we converted the predict-to grid into a 1-km^2 raster to create a predictive map of the occurrence for Smith's Longspur. We then classified the resulting continuous occurrence prediction scores into predicted presence or absence for the distribution map using a threshold occurrence score. Occurrence scores at or above the threshold were classified as presence. To identify a broad area of predicted occurrence and potentially suitable habitat, we used a threshold of 0.22, where sensitivity (proportion of presence points correctly classified) equalled specificity (proportion of absence points correctly classified). We also used a higher threshold of 0.45, where the sum of sensitivity and specificity was maximized, to identify areas with high probability of occurrence areas or highly suitable habitats (Liu et al. 2005).

We evaluated the predictive distribution map by its ability to correctly predict presence or absence. To do this, we used the previously withheld evaluation dataset (presence n = 75; absence n = 275). For each of these points, we extracted predicted occurrence scores from the distribution map and compared them to survey results to calculate the area under the curve (AUC). This threshold-independent measure assessed the ability of our map to predict Smith's Longspur presence and absence points (Pearce and

Ferrier 2000, Fielding and Bell 2002). AUC scores range from 0-1, where a score of 1 indicates perfect discrimination, a score of 0.7 indicates acceptable discrimination, and 0.5 indicates discrimination that is no better than random (Manel et al. 2001). We calculated AUC using ROC_AUC software (Schroeder 2004). We also evaluated our predicted distribution using classification matrix measures that are threshold dependent. The classification matrix included four elements: correct and incorrect presence predictions and correct and incorrect absence predictions. From the classification matrix we calculated sensitivity, specificity, and overall percent correct (Kohavi and Provost 1998). We chose a threshold occurrence score that minimized difference between sensitivity and specificity because of its good performance (Schroeder and Richter 1999, Jimenez-Valverde and Lobo 2007).

RESULTS

We surveyed 1,164 points in 12 study sites for Smith's Longspur occurrence and local habitat characteristics. Of the 829 points surveyed in non-forested habitats, we detected Smith's Longspurs at 30% (n = 248). Frequency of occurrence at survey points within the seven sites where longspurs were detected ranged from 17-65% (Fig. 1.1). These sites included two river valleys situated within the tundra-forest transition zone and five large tundra valleys; four were along the northern edge of the ecoregion and one was along an east-flowing river in the westernmost study site. Longspurs occurred at elevations from 331–1109 m (average 645 ± 163 m) across the range of elevations sampled (226–1114 m). The average slope where they were found was 12º ± 12º, and 30% of presence plots had slopes <5º. Occurrence was scattered across all aspects: 27% in the northeast quadrant, 22% in the southeast quadrant, 21% in the southwest quadrant, 27% in the northwest quadrant; only 4% occurred on flat slopes.

Local habitat associations

The valley landscapes we sampled in the Brooks Range often consisted of a mosaic of distinct habitat types; approximately two thirds of all plots sampled were classified with two or more habitat types. As a result, the average cover of many habitats did not exceed 50% (Fig. 1.2). We found Smith's Longspurs in a variety of habitats, but they

most frequently occurred in sedge tundra, dwarf scrub, and open scrub habitat types (Appendix 1.1). Average cover of habitat types varied between presence and absence plots, but high variability indicated that differences in cover would not be statistically relevant.

Smith's Longspur habitat was composed primarily of sedges and moss with limited cover of dwarf and low shrubs (Table 1.1). Sedges and moss were found at nearly every plot where longspurs occurred and had the highest average cover. Both non-tussock and tussock sedges were commonly associated, however non-tussock sedges had higher average cover and frequency of occurrence. Compared to plots where longspurs were absent, non-tussock sedges were more frequently found on plots where longspurs occurred. Moss was common at all non-forest plots but average cover was greater on presence plots. The most widespread dwarf shrubs were *dryas* and dwarf willow; both occurred at approximately two-thirds of all presence plots. Other dwarf shrubs included various ericaceous species with low average cover. Willow and birch were common in all non-forest plots; where longspurs were found, cover of shrubs was typically low and frequency and maximum cover of shrubs was lower than was found on absence plots. At presence plots average willow and birch height was low: 0.7 ± 0.5 m and 0.6 ± 0.4 m respectively.

Representing differences in vegetation composition among non-forest plots (n = 762), the three axes of the NMS ordination cumulatively explained 86% of the variation in ground cover (axis 1: r^2 = 0.27; axis 2: r^2 = 0.33; axis 3: r^2 = 0.26; final stress = 14.8; P < 0.02). Axis 1 had a negligible correlation with Smith's Longspur presence and separated tussock habitats with birch and ericaceous shrubs from tall willow habitats (Table 1.2). Axes 2 and 3 had the strongest correlation with Smith's Longspur occurrence and are used to display the ordination (Table 1.2; Fig. 1.3). Axis 2 separated non-tussock sedge and dwarf shrub habitats from tall shrub and woodland habitats. Axis 3 separated non-tussock sedge habitats with high moss cover from habitats with higher cover of willow, birch, and Labrador tea. Plots where Smith's Longspur occurred were clustered in the middle and lower part of the ordination reflecting an association with greater cover of mosses and sedges, and to a lesser degree with cover of lichens, dwarf willow, *dryas*,

and heather. Correlation with environmental variables showed these associated habitats were found closer to the northern coastline and at higher elevations. Although a few presence plots had higher shrub cover, there was a general negative association with greater cover of birch, willow, and alder shrubs.

Predicted distribution

Our distribution model successfully predicted Smith's Longspur occurrence across the Brooks Range ecoregion (AUC = 0.83; Fig. 1.4). At the 0.22 threshold, sensitivity, specificity, and overall correct classification rates were 73%, with 56 of the 75 presence points used to evaluate the predicted map classified correctly, and 202 of the 275 absence points classified correctly. At this lower threshold, we predicted Smith's Longspur occurrence on 14% (~2.2 million ha) of the 15.5 million ha study area. Most of these presence predictions had low probability of occurrence: 40% of the points where presence was predicted had occurrence scores between 0.22-0.29; 30% were 0.3-0.39; 17% were 0.4-0.49; 8% were 0.5-0.59, 3% were 0.6-0.69 = 3%; and only 1% were ≥0.7. Using a threshold of 0.45 to identify areas with a higher probability of occurrence, we predicted only 2.5% of the study area (396,100 ha) to have Smith's Longspur present. At this higher threshold, sensitivity dropped to 37% with only 28 of the 75 presence points correctly classified, specificity increased, with 93% of the absence points correctly classified (256 of 275), and the overall correct classification rate increased to 81%.

Our BRT model contained 312 trees and used all seven landscape variables to model Smith's Longspur occurrence. BRT scored the relative importance of variables based on their contribution to reducing variance in the model: ecotype (100), distance to coast (93), elevation (73), distance to river (66), surface geology (61), slope (60), and aspect (50). Smith's Longspurs were positively associated with sedge and shrub tundra ecotypes and negatively associated with barrens, water, and forest ecotypes (Fig. 1.5, Appendix 1.2). Only two of the 12 surface geology classes, lightly modified moraine and moderately modified moraine, were positively associated with Smith's Longspur presence. The partial dependence plots for topographical variables depicted an association with points within 250 km of the coast, approximately 400-1000 m above sea level, and <1500 m from rivers, with weaker support for sites <100 m from rivers (Fig.

1.6). North- and east-facing slopes up to 35º were associated with longspur presence, with the strongest association for sites with <5º slope.

With the predicted distribution map, we predicted that Smith's Longspur are distributed across several areas in the Brooks Range. Large areas of predicted presence are located in the eastern Brooks Range, primarily within the river valleys and foothill slopes along the northern front of the mountains from the Kongakut River to the Killik River; along the southern front, Smith's Longspurs occurrence was predicted in several large river valleys from the Canadian border to just west of Arctic Village. In the west, presence was predicted primarily in upland areas and broad mountain passes surrounding the large Noatak River valley.

DISCUSSION

Our study was the first effort to characterize the breeding habitat and distribution of Smith's Longspurs across a large geographic area, and the only habitat study specific to the northwestern range of the species. As in previous accounts within the Brooks Range (Irving 1960, Sage 1976, Briskie 2009), we found prevalence of Smith's Longspurs was low, however this uncommon species was locally abundant within various tundra habitats situated in broad tundra valleys and low-mountain slopes. We documented many breeding areas for Smith's Longspurs and due to high breeding site fidelity (Briskie 2009), these areas will likely continue to be occupied making these breeding areas important for conservation of this uncommon species of concern. In addition to monitoring populations, the various locations where Smith's Longspurs were found is important information for designing future studies into various aspects of their breeding ecology.

Habitat associations

At both the local and landscape scale, Smith's Longspurs were associated with heterogeneous landcover of sedge and shrub habitat types. The correspondence between local habitat and ecotypes strengthens our conclusions and the use of ecotype as the most important variable for predicting distribution. In general, Smith's Longspur were associated with ground cover characterized by sedges and moss with variable

amounts of dwarf and low shrubs; patches of dense shrubs or trees were sometimes present interspersed within sedge-shrub tundra, but sites with large patches of closed shrub cover appeared to be avoided. Because Smith's Longspurs typically walk on the ground to forage in sedges, moss, and dwarf shrubs (Irving 1960, Sage 1976, Briskie 2009), we expected to find the species associated with a variety of sedge tundra and dwarf scrub types. However, their association with open scrub habitat (25-75% shrub cover) was unexpected. Across the study sites, open scrub habitat was the most common type and was found at the majority of presence and absence points. This is reflective of how widespread shrubs were in the ecoregion, but also due to the broad level of classification used to characterize open scrub habitat. It is likely that there is some maximum threshold of shrub cover for use by Smith's Longspurs, which likely varies by shrub species and lies within the range we used to classify open scrub habitat. Shrubs provide vertical structure that provides cover for nests, protection from predators, refuge during inclement weather, and perches for broadcasting songs and observing intruders (Jehl 1968, T. Wild, personal observation). Additionally, the use of different shrub communities for foraging is not understood. For example, we found that riparian ecotypes were negatively associated with Smith's Longspur presence, yet birds were observed occasionally making foraging trips to riparian shrub habitats (T. Wild, personal observation); proximity to riparian shrub habitats may be important at a larger scale than measured. It is likely that shrub habitats will become more widespread and more closed in response to climate change; further investigations into the relationship between scrub habitats and breeding ecology should explore thresholds of shrub cover and the suitability of different types of scrub habitats.

At the local scale, ground cover at many of the absence points was similar to presence points, which may indicate that either suitable habitat was not saturated by Smith's Longspurs, or other factors that we did not quantify limited occurrence. It is possible that the habitat in those absence plots was suitable for Smith's Longspurs, but the species was not detected due to their behavior, observer error, survey timing, or survey conditions. However, we ostensibly maximized detectability by adequately training personnel, timing surveys to correspond with peaks in singing, and conducting surveys in good weather. We did not include landscape mosaic as a habitat variable; Smith's

Longspurs may select breeding areas based on habitat composition beyond the scale of 100-m radius plots. Smith's Longspurs are not territorial but form neighborhoods of interbreeding males and females with large home ranges (males 9.4-30.9 ha; females 5.4-19.5 ha; Briskie 2009). The number of birds in a neighborhood is likely influenced by the landscape composition and the size of suitable habitat (Jehl 1968). Because of this unique breeding system, a mosaic of local habitats may be preferred over more homogenous landscapes on a neighborhood rather than a territory scale. Questions of habitat suitability and saturation remain important for conservation and management and future research efforts should assess the effects of scale and habitat heterogeneity on the abundance/occupancy, home range size, and survival/breeding success of Smith's Longspurs.

Predicted distribution

We predicted that Smith's Longspurs range across a wide portion of the Brooks Range, but their distribution across the ecoregion is limited because rugged mountains and other unsuitable habitats such as forests, barren ridges, rivers, and lakes characterize much of the ecoregion. We used a lower threshold of occurrence to identify a broad area of potentially suitable habitat. At this threshold the percentage of correct presence predictions was 73%, but the trade-off involved more false predictions of presence. Due to the uncommon occurrence of the species and an indication that some suitable habitats are not occupied, we would expect the Smith's Longspurs to be absent in some areas with suitable habitat and therefore expect higher numbers of false presence predictions. Using a higher threshold, we identified areas with a higher probability of occurrence. At this threshold the area predicted to be suitable was reduced from ~2.2 million ha to 396,100 ha. We have more confidence in our predictions with higher probability of occurrence because they coincided with known or probable breeding areas (Gotthardt and Jansen 2004). At this higher threshold, more presence points were incorrectly classified, indicating that many birds were found outside the area of high probability of occurrence.

Although large forested valleys and rugged mountains in the Brooks Range limit suitable habitat, we predicted that Smith Longspurs may occur in many of the valleys and

foothills. The model predicted presence in the southeastern valleys and included areas where breeding longspurs were observed previously (Kessel and Schaller 1960, Spindler et al. 1980). However, due to the gap in coverage of the most important variable, ecotype, our model could not differentiate among habitats in this area and therefore predicted presence in the forested parts of these valleys were likely false. In the northeast region, large areas of predicted presence along the northeastern edge suggests that Smith's Longspurs may also be found farther north than previously thought, in adjacent portions of the Brooks Foothills bioregion (Nowacki et al. 2001).

In the valleys west of Anaktuvuk Pass our model predicted presences in only a few, small areas. Anaktuvuk Pass was once thought to mark the western extent of Smith's Longspurs' breeding range (Sage 1976); reasons for their absence in the valleys farther west are still not clear. Our surveys in this region were limited to navigable river valleys, leaving the broad tundra passes and headwater valleys unsurveyed. Suitable habitat may exist in upland areas that were not identified in our model due to limited extent of our surveys. In addition, the high importance assigned to distance to coastline may be driving down prediction scores due to the shape of the coastline in relation to the Brooks Range. Predicted absence in the tundra valleys and uplands west of Anaktuvuk Pass should be confirmed with more targeted surveys in this area.

Our model identified many areas in the montane uplands of the western Brooks Range as potential habitat for Smith's Longspurs, far outside the presumed western boundary of the species' range (Gotthardt and Jansen 2004). To date, most of this area has not been surveyed for breeding landbirds, and the extent of the species' western distribution remains uncertain. The accuracy of our predictions there are unknown because we had no test data from the region. However, an inventory of montane-nesting birds in the western and central Brooks Range in 2001-2003 detected Smith's Longspurs in areas where we predicted presence (Tibbitts et al. 2005). Anecdotal reports also suggest that Smith's Longspurs are breeding near the northern edge of the ecoregion near the headwaters of the Utukok and Colville Rivers (Patricia Reynolds, USFWS, personal communication). Focused surveys in the western Brooks Range are needed to refine our understanding of Smith's Longspur distribution in that region.

Our predicted distribution reflected the bias toward valleys and does not represent potentially suitable habitat such as tundra basins and passes at higher elevations with greater distances to rivers. The ability of our model to identify these areas was not reflected in our evaluation measures, because our evaluation data came from the same study sites used to make the prediction. However, with so little known about Smith's Longspur distribution, our intent was to develop a model to understand habitat associations and locate potential breeding areas. Species distribution modeling is an iterative process (Elith and Leathwick 2009); future work should refine the predictive model by incorporating new occurrence information and spatial landscape data as they become available.

Climate change

Dramatic changes associated with climate warming are predicted for northern Alaska, including advance of tree line, increased shrub abundance and growth, and decreased moss cover and soil moisture (Hinzman et al. 2005, Euskirchen et al. 2009). Climatically driven changes to vegetation communities have already been documented; shrubs are becoming larger and more abundant (Tape et al. 2006, Euskirchen et al. 2009). Shrubs, particularly willow, birch, and alder, are increasing primarily in valleys and on hill slopes, especially south-facing slopes. It is likely that shrubs have already increased in some areas where Smith's Longspurs occur. As conditions in the tundra increasingly favor shrub and tree growth, more open tundra habitats may be lost, which could negatively affect longspurs populations in the Brooks Range. We found that longspurs used tundra habitats that sometimes had patches of willows and birch; however, they were not found in areas with large expanses of dense shrubs. How Smith's Longspurs respond to increasing shrubs will depend largely on the patterns of shrub growth and the persistence of sedges and moss in the understory. In fact, increasing shrub growth in sedge tundra habitats could form the sedge-shrub tundra preferred by Smith's Longspurs, but a reduction in soil moisture and moss cover may drastically alter preferred habitat. As the climate gets warmer and drier, sedge-shrub tundra in the Brooks Range will likely persist in poorly drained lowlands and moist alpine basins. On the other hand, suitable sedge-shrub tundra is likely to follow the northern advance of

the tundra-forest transition zone and Smith's Longspur distribution may adapt to the shifting distribution of preferred habitat. Breeding Smith's Longspurs have been documented along the Dalton Highway north of the Brooks Range (Meddle et al. 2003) and as far north as the transition from the foothills to the flat coastal plain (T. Wild, personal observation) indicating that northern habitats may be suitable. However, the extent to which Smith's Longspurs will persist in increasingly shrubby sites or occupy new sites is uncertain due to apparent breeding-site fidelity (Jehl 1968).

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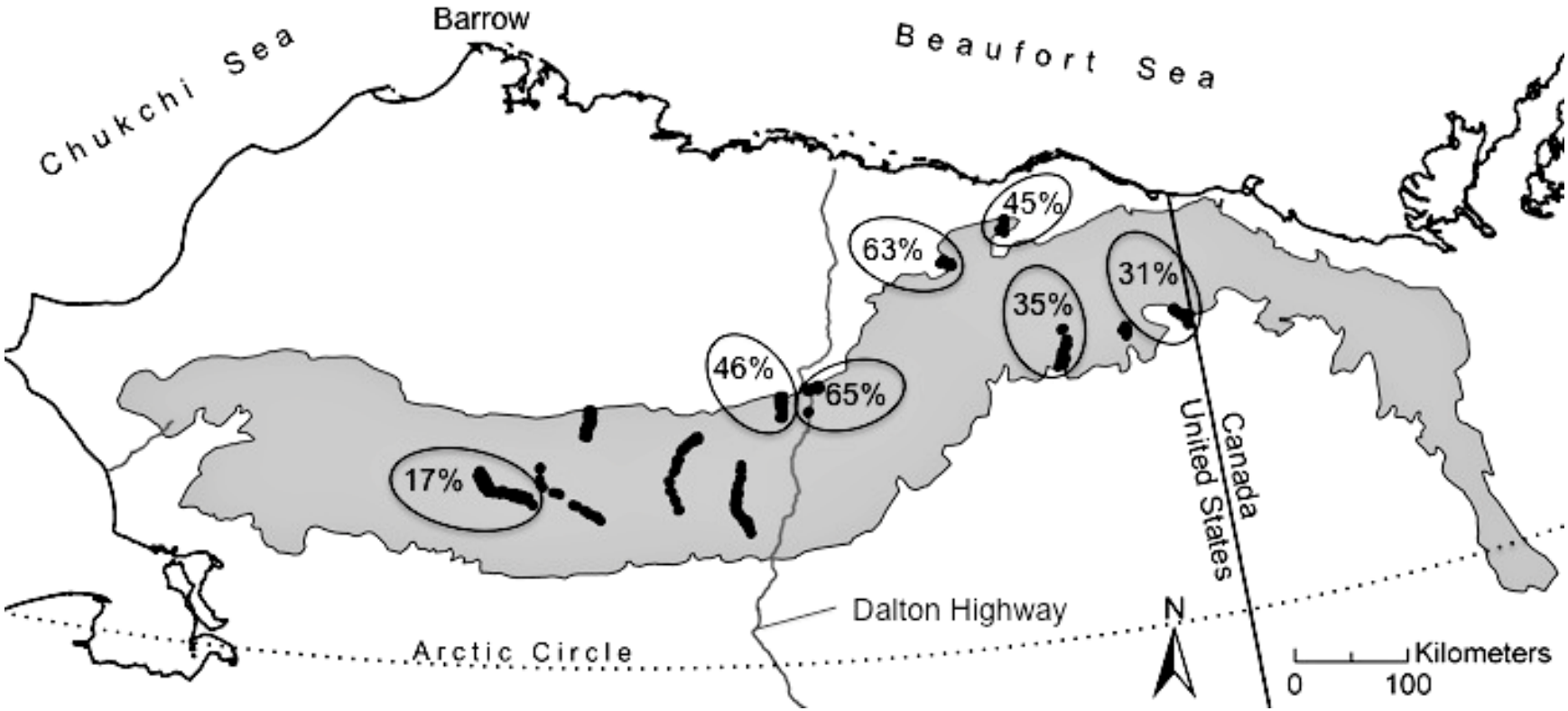

Fig. 1.1 The Brooks Range Ecoregion (Nowacki et al. 2001) and the location of points surveyed (n = 1164) for Smith's Longspurs at 12 study sites. Smith's Longspurs were detected in the seven circled sites at 248 points; numbers represent the prevalence of occurrence, calculated as the percentage of points in each site where longspurs were present. The sites east of the Dalton Highway were surveyed in the Arctic National Wildlife Refuge (2006−2009) and western sites were surveyed in Gates of the Arctic National Park and Preserve (2003−2009).

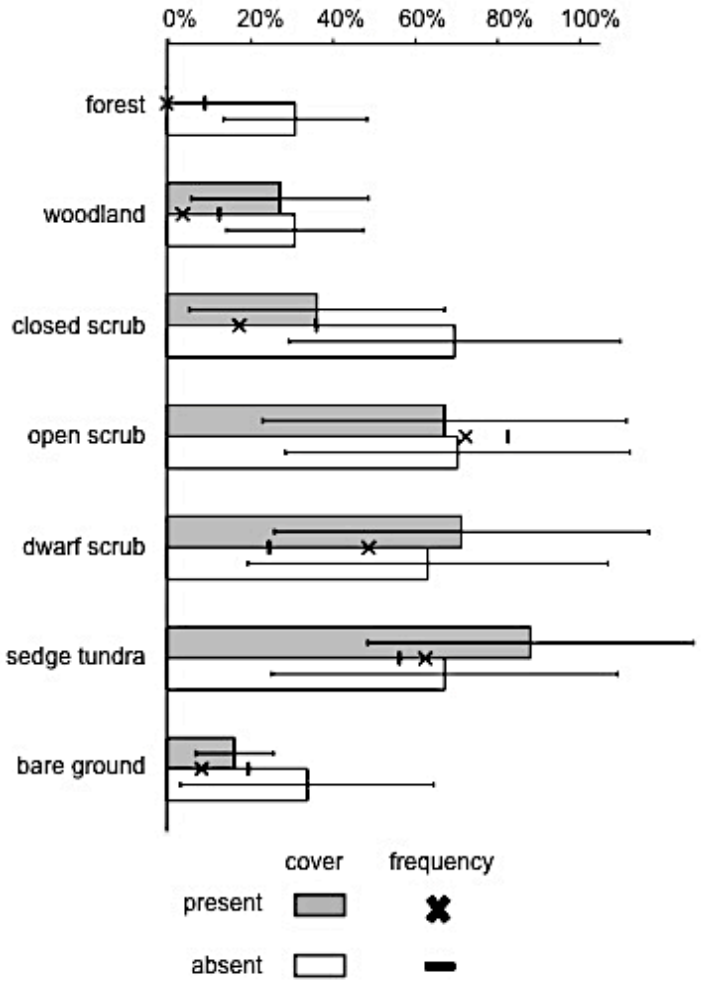

Fig. 1.2. Average cover ± SD (%) and frequency of occurrence (%) of habitat types classified at 100-m plots where Smith's Longspurs were present (n = 182) and absent (n = 580) in non-forested plots (<50% forest cover) in the Brooks Range, Alaska. Habitat classification was based on the structure and composition of dominant vegetation following the Alaska Vegetation Classification key defined by Viereck and Station (1992). Cover was the average proportion of each habitat type across presence and absence plots. Classes that occurred on <5% of plots are not shown.

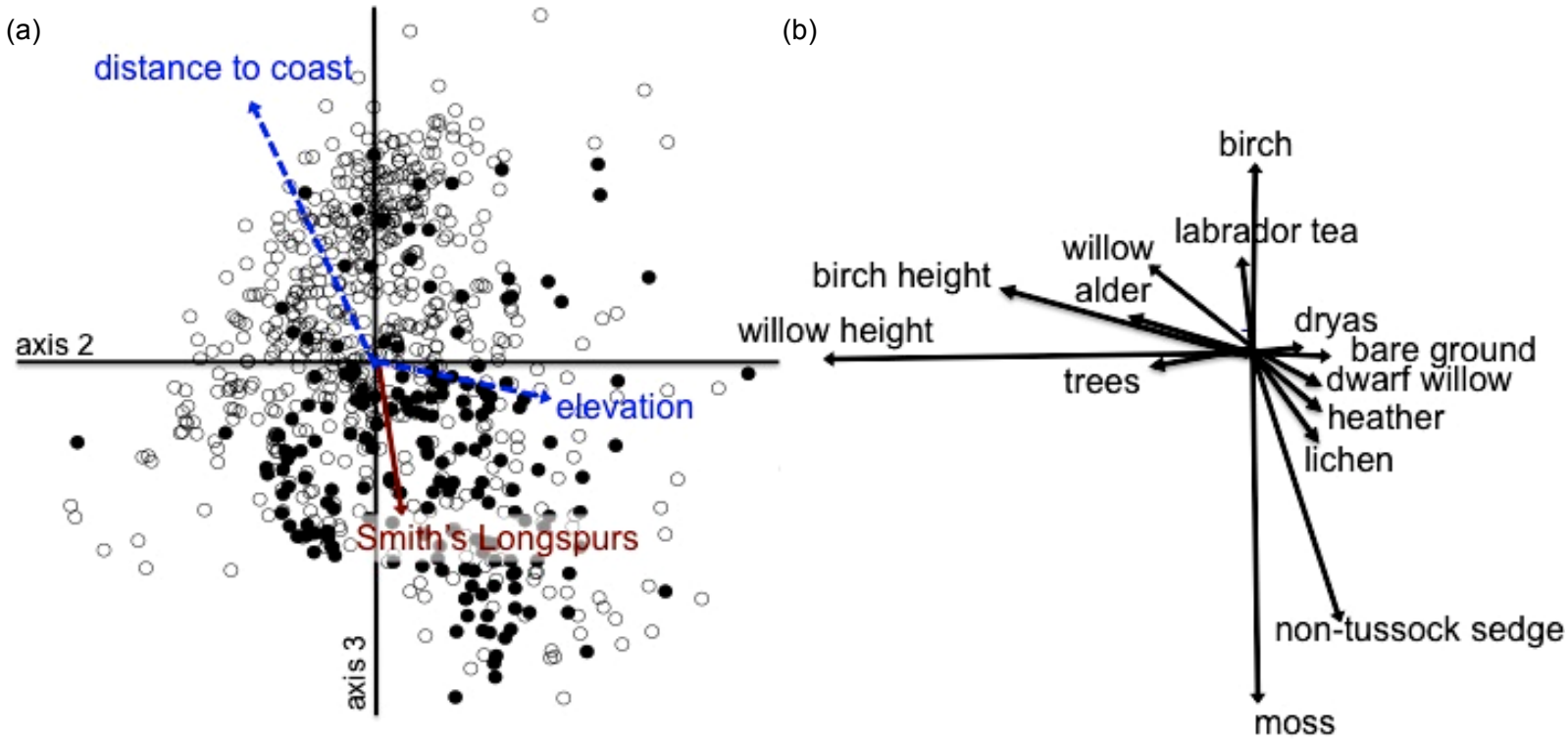

Fig. 1.3 (a) Axes 2 vs. 3 of the 3-dimensional nonmetric multidimensional scaling (NMS) ordination of ground cover measured at non-forested local habitat plots where Smith's Longspur were present (●; n = 182) and absent (○; n = 580) in the Brooks Range, Alaska. Plots were situated in the diagram by NMS according to the similarity of ground cover composition. NMS vectors showed the strength and direction of correlations with Smith's Longspur occurrence (red line) and landscape characteristics (blue dashed line). Habitats where longspurs occurred were clustered in the middle and lower part of the ordination correlating with higher elevation habitats or those closer to the coast. (b) The corresponding NMS vector diagram showed the strength and direction of correlations of ground cover components (black lines). Only components with r≥|0.2| are shown, reflecting a positive association with moss and sedge cover and negative association with birch, willow and alder cover.

Fig. 1.4 Predicted distribution of Smith's Longspur (*Calcarius pictus*) in the Brooks Range, Alaska (AUC = 0.83; correct classification of evaluation data = 73%), identifying associations with uplands in the west and valleys and hillsides in the east. Within the ecoregion study area (black dashed line), areas of predicted occurrence are shown in blue and red. Blue areas had low occurrence scores 0.22-0.44 and represent potentially suitable habitat. Red areas also represent suitable habitat but had high occurrence scores (≥0.45). The ecoregion was divided to separate the western region where Smith's Longspur occurrence is less certain.

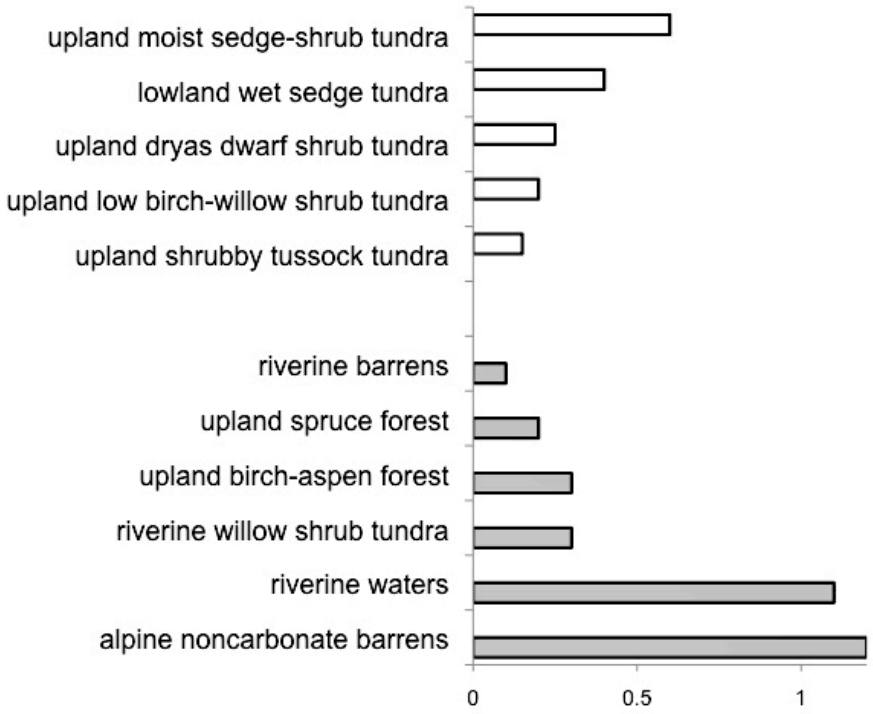

Fig. 1.5 Partial dependence scores for landcover ecotype classes from a boosted regression tree (BRT) analysis of Smith's Longspur distribution in the Brooks Range, Alaska. White bars show positive partial dependence and indicates the ecotypes associated with Smith's Longspurs. Grey bars show negative partial dependence and reflects a negative association with Smith's Longspurs. Categories with partial dependence < |0.1| are not shown.

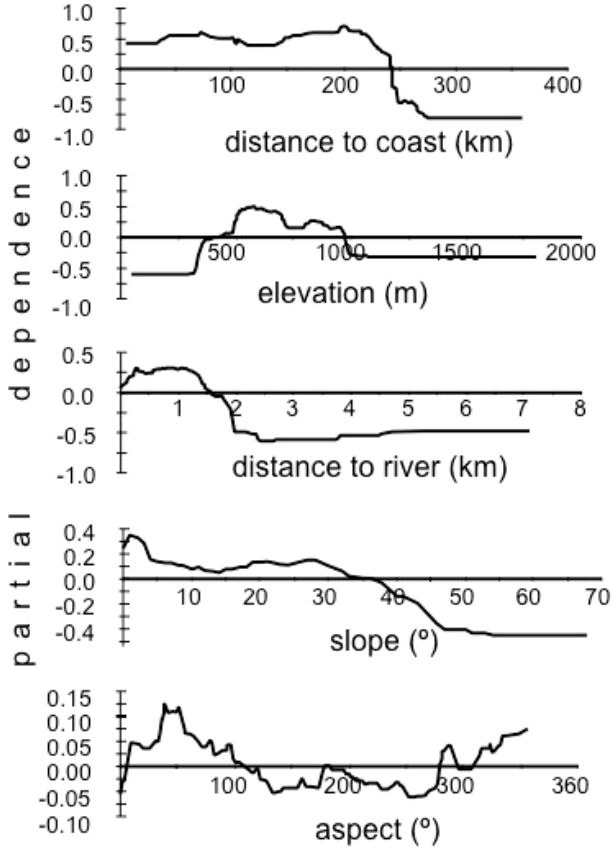

Fig. 1.6 Partial dependence plots of topographical variables from a boosted regression tree (BRT) analysis of Smith's Longspur distribution in the Brooks Range, Alaska. The graphs show the individual relationship of topographic variables to the occurrence of Smith's Longspur: positive values suggest longspurs are associated with those features and low values suggest the opposite.

Table 1.1 Average and maximum cover (%) and frequency of occurrence (%) of ground cover components within 100 m radius of non-forested points surveyed for birds in the Brooks Range, Alaska, June 2003-2009. Results were grouped by Smith's Longspur occurrence (present, n = 182 and absent, n = 580). Average cover values are presented as mean (%) ± SD. Frequency of occurrence is the percentage of presence or absence points where the ground cover type was found.

ground cover	average cover maximum cover		frequency	
	present	absent	present	absent
TREES			10	20
deciduous trees[†]	<0.1 <0.1	0 ± 2 23	1	6
black spruce (*Picea mariana)*	-	0 ± 1 16	0	4
white spruce (*P. glauca)*	<0.1 0.1	0 ± 214	9	14
SHRUBS			92	97
willow (*Salix* spp.)	13 ± 13 59	20 ± 21 90	83	90
birch *Betula* spp.	7 ± 10 48	15 ± 17 95	54	72
alder (*Alnus* spp.)	0 ± 1 14	2 ± 7 80	2	12
labrador tea (*Rhododendron* spp.)	1 ± 4 20	4 ± 7 48	18	33
blueberry (*Vaccinium uliginosum)*	3 ± 5 31	2 ± 5 56	37	49

Table 1.1 continued…

buffaloberry (*Sheperdia Canadensis)*	-	0 ± 1 17	0	3
DWARF SHRUBS			94	81
lapland rosebay (*Rhododendron lapponicum)*	2 ± 5 35	1 ± 4 60	34	20
lingonberry (*Vaccinium vitis-idaea)*	2 ± 5 48	3 ± 8 68	19	26
crow berry (*Empetrum nigrum)*	1 ± 4 38	1 ± 3 25	14	16
dryas (*Dryas* spp.)	12 ± 17 80	7 ± 12 80	75	52
dwarf willow (*Salix* spp.)	9 ± 9 45	4 ± 8 60	73	40
bear berry (*Arctostaphylos* spp.)	1 ± 3 18	2 ± 4 44	15	25
heather (*Cassiope* spp.)	2 ± 5 40	1 ± 3 39	23	12
FORBS‡			46	33
misc. herbs	2 ± 4 35	1 ± 3 32	28	12
horsetail (*Equisetum* spp.)	3 ± 8 55	2 ± 7 70	31	24

Table 1.1 continued…

SEDGES			93	66
tussock	13 ± 18 80	17 ± 25 100	62	53
non-tussock	23 ± 22 100	8 ± 18 99	81	29
OTHER				
moss	67 ± 30 100	38 ± 32 100	97	90
lichen	9 ± 12 67	5 ± 10 62	69	51
bare ground§	2 ± 7 60	1 ± 6 70	20	10
water|	6 ± 17 96	5 ± 13 90	27	28

† paper birch (*Betula neoalaskana),* balsam poplar (*Populus balsamifera),* and quaking aspen (*P. tremuloides).*
‡ *Andromeda polifolia*, bear flower (*Boykinia richardsonii)*, fireweed (*Chamerion angustifolium), dwarf fireweed (C. latifolium), lousewort (Pedicularis* sp.), and wintergreen *(Pyrola* s*p.)*
§ sand, gravel, mud, soil, and talus
| river, creek, lake, and pond

Table 1.2 Pearson's correlations (r) of variables with the three axes of the NMS ordination of local ground cover measured on unforested habitat plots centered on points surveyed for Smith's Longspurs in the Brooks Range, Alaska in June 2007-2009. Only variables with r ≥ |0.20| (shown in bold) for at least one of the three axes are shown.

variable	axis 1	axis 2	axis 3
Smith's Longspurs	0.10	**0.21**	**-0.37**
deciduous trees	-0.14	**-0.28**	-0.03
white spruce	-0.05	**-0.23**	0.03
willow	**-0.52**	**-0.20**	**0.20**
willow height	**-0.40**	**-0.77**	-0.10
birch	**0.22**	-0.12	**0.46**
birch height	0.19	**-0.29**	0.13
blueberry	**0.30**	-0.05	0.06
Labrador tea	**0.38**	-0.05	**0.20**
alder	0.06	**-0.22**	0.05
lingonberry	**0.30**	-0.05	0.06
heather	0.10	**0.25**	**-0.22**
bear berry	**-0.25**	-0.10	0.14
dwarf willow	-0.03	**0.23**	-0.19
dryas	**-0.20**	**0.24**	-0.05
tussock sedge	**0.63**	-0.01	0.18
non-tussock sedge	**0.31**	**0.34**	**-0.57**
moss	**0.38**	0.09	**-0.64**
lichen	**0.23**	**0.28**	**-0.27**
bare ground	-0.11	**0.31**	-0.08
distance to coast	**-0.33**	**-0.35**	**0.56**
elevation	0.13	**0.49**	**-0.22**
slope	0.12	**0.23**	0.01

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Appendix 1.1 Frequency of all Viereck level III habitat classes at points where Smith's Longspur were present (n = 182) and absent (n = 580) on bird surveys conducted June 2003-2009 in the Brooks Range, Alaska. To focus on potential habitat among tundra and woodland habitats, sites with >50% forest cover were excluded. Frequency is the percentage of points where the habitat class was found.

	Frequency (%)	
Viereck habitat class	Present	Absent
forest	0	8
woodland	2	11
closed tall scrub	1	7
closed low scrub	13	24
open tall scrub	4	12
open low scrub	56	59
dryas dwarf scrub	20	10
willow dwarf scrub	15	4
ericaceous dwarf scrub	7	7
wet graminoid herbaceous	15	15
mesic graminoid herbaceous	42	30
dry herbaceous	4	3
bare ground	6	15

Appendix 1.2 Frequency of all ecotype classes for Smith's Longspur presence (n=248) and absence (n=916) points surveyed during June 2003-2009 in the Brooks Range, Alaska.

Ecotype class	Frequency (%)	
	Present	Absent
riverine	0	0
waters	0	4
barrens	1	1
wet sedge tundra	0	1
moist sedge-shrub tundra	4	5
dryas dwarf shrub tundra	2	3
willow shrub tundra	0	2
alder willow shrub	1	1
balsam poplar forest	0	1
spruce forest	1	5
spruce-balsam poplar forest	0	1
lowland		
lake	2	1
wet sedge tundra	2	1
low birch-willow shrub	2	4
spruce forest	2	3
upland		
dryas dwarf shrub tundra	5	4
shrubby tussock tundra	14	11
low shrub birch-willow tundra	19	17
moist sedge-shrub tundra	22	8
tall alder shrub	2	3
spruce forest	0	4
birch-aspen forest	0	0
birch-aspen-spruce forest	0	0
Alpine		
noncarbonate barrens	0	1
noncarbonate dwarf shrub tundra	6	2
no coverage	4	5
Cloud	10	14

CHAPTER 2

ESTIMATING ABUNDANCE OF AN UNCOMMON SPECIES ACROSS THE BROOKS RANGE, ALASKA[1]

ABSTRACT

Smith's Longspur (*Calcarius pictus*) is a species of concern, yet few studies have been conducted on their breeding grounds in Alaska. To date, broad-scale monitoring programs have not adequately evaluated their populations, largely because of limited observations due to the rarity of the species. We conducted point count surveys on 88 routes for Smith's Longspur at nine sites within the Brooks Range in June 2003–2009. Using multi-covariate distance sampling, we estimated density and evaluated the effects of observer and environmental conditions on detection. At one site, we conducted replicate surveys to determine the best timing for surveys and evaluate the effectiveness of two common distance-sampling methods: point and line surveys. We modeled detectability using observations of 353 males on point counts, pooled across all sites and years, and estimated average density of 0.13 males/ha, with highly variable site estimates ranging from 0–0.39 males/ha. We found that density varied largely due to the patchy distribution of Smith's Longspur within and among sites. Surveys repeated within a season indicated the importance of survey dates and suggested that peak detectability of males was during the first two weeks of June, with detections decreasing after incubation commenced. We also evaluated point and line surveys for Smith's Longspur and showed point surveys were effective for estimating density and did not violate distance sampling assumptions. Line surveys methods may have violated distance-sampling assumptions resulting in estimates that were biased low. Finally, we used our density estimates to calculate approximately 10 000–30 000 males in the Brooks Range. From this study we gained a better understanding of the wide variability in distribution and abundance of Smith's Longspurs in northern Alaska and made recommendations for improve survey effectiveness.

[1]**Wild, T., S. Kendall, and A. Powell.** Estimating abundance of an uncommon species across the Brooks Range, Alaska. Prepared for submission to *Journal of Field Ornithology.*

INTRODUCTION

For many landbirds, information on population size and trend is lacking or inadequate for conservation and management (Rich et al. 2004). This is often due to limited coverage of broad-scale monitoring programs in some regions such as the Arctic. In addition, the survey methods used by broad scale multi-species studies may not adequately assess populations of some uncommon or difficult to detect species (McDonald 2004) for which other means of population assessment are needed (Rosenstock et al. 2002, Simons et al. 2007). Finally, forecasted climatic changes to arctic tundra could lead to dramatic changes for the breeding habitats of 15% of the world's bird species (Wormworth and Mallon 2006, North American Bird Conservation Initiative 2010). Without baseline information and monitoring, we cannot predict the impact of forecasted ecological changes to avian populations.

One arctic-nesting species for which little is known is the Smith's Longspur (*Calcarius pictus;* Sage 1976, Boreal Partners in Flight 1999, Briskie 2009). Little is known about the species' population size or trends due in part to their remote breeding grounds, where few birds are detected using broad-scale monitoring programs such as the Breeding Bird Survey (BBS; Rich et al. 2004) and Alaska Landbird Monitoring Survey (ALMS; Handel and Cady 2004). Surveys targeted to detect Smith's Longspurs are needed to assess and monitor their populations. The species is considered "vulnerable" due to uncertainty surrounding a small maximum population size (roughly estimated at <75 000 birds), and geographically small wintering range characterized by intensive human use (Briskie 2009).

The current total population estimate was derived from an extrapolation based on 300 birds along 21 km of treeline in the eastern portion of the breeding range near Churchill, Manitoba, Canada; it was assumed that breeding densities and amount of suitable habitat did not vary across the 5000-km long breeding range (Briskie 2009). In general, only a few anecdotal accounts provide information on the abundance and distribution of Smith's Longspurs across their breeding range (Irving 1960, Kessel and Schaller 1960, Weedon 1960, Sage 1976, Manuwal 1978, Gotthardt and Jansen 2004).

The westernmost breeding distribution of Smith's Longspurs occurs in Alaska, where they breed primarily along the northern edge of the Brooks Range. They are also found in small numbers along the elevational transition zone in alpine tundra in the interior and southeastern part of the state (Gotthardt and Jansen 2004). The core of the breeding population in Alaska is suspected to be in the northern foothills and valleys of the eastern Brooks Range, where they are locally common but not widespread. Over 75% of the Brooks Range in Alaska is managed by two federal land management agencies: the National Park Service (NPS) and U.S. Fish and Wildlife Service (USFWS). Although these agencies are charged with conserving migratory bird species, so little is known about Smith's Longspurs in Alaska that conservation planning for the species is hindered. To provide baseline data on Smith Longspur populations in this region, we conducted surveys over a broad scale to identify important breeding areas and to estimate local densities across the Brooks Range. We used multi-covariate distance sampling (MCDS) with point survey methods to estimate densities and assess the effects of observer performance and various environmental covariates. We also conducted replicate surveys at one site to determine the best timing for surveys and evaluate the effectiveness of point versus line survey methods for estimating densities of Smith's Longspur. Finally, we used our density estimates to calculate a population size for Smith's Longspurs in their westernmost range.

METHODS

Study area. We surveyed for Smith's Longspurs at nine sites within the Brooks Range, Alaska, where they breed in the broad river valleys and foothills on the north and south side of the Range (Gotthardt and Jansen 2004). The Brooks Range is the northernmost mountain range within Alaska. Made up of many smaller ranges and river valleys, it runs east-west across Alaska and extends over 700 kilometers from the Chukchi Sea on the west coast to the Canadian Beaufort Sea in the east.

The Brooks Range divides the arctic tundra from the boreal forests of interior Alaska. To the north, tundra and shrub habitats characterize river valleys and low mountain slopes. The Arctic tree line extends across the south side of the mountain

range; within this tundra-forest transition zone, sparse spruce forests and shrubbery with patches of tundra meadows characterize valleys and low slopes. Barren and rugged terrain characterizes the alpine ridges and steep slopes across the range.

The 15.6-million-ha Brooks Range ecoregion (Nowacki et al. 2001) is a remote area with only a few small communities and human developments. The Dalton Highway provides the only road access across the mountain range. During the summer breeding season, access is possible primarily by float or wheel equipped airplanes.

Field methods. We surveyed six valleys with tundra habitat and three valleys in the tundra-forest transition zone with reported or suspected breeding populations of Smith's Longspurs (Table 2.1, Fig. 2.1). These sites either had road access or landing sites for small airplanes. Within each site, we selected survey points from a 500-m point grid; survey routes, each consisting of 10-12 sequential points, were evenly distributed within study sites using sequential random sampling. Access to survey points within sites varied as some sites allowed for river travel between routes, while others required observers to backpack to access survey routes.

At all sites, except Atigun Gorge, one survey was conducted during a breeding season. At Atigun Gorge, Itkillik, and Noatak, surveys were conducted in multiple years (Table 2.1). At Atigun Gorge, where a highway allowed us easy access, we surveyed routes three times in 2007, twice in 2008, and once in 2009 to examine variability within a season and among years. In 2007 and 2009, we conducted point and line surveys simultaneously in order to evaluate effectiveness of the two survey methods for estimating density.

We recorded all species seen or heard within a 10-minute period for point surveys at all sites. However, for line surveys at Atigun Gorge, we recorded detections of Smith's Longspurs only, and ignored other species detected to reduce the load on observers tasked with navigating a line transect and tracking birds. Line surveys were conducted while traveling at a steady pace on a bearing between the points sampled for point surveys. Distance of the bird from the point was recorded for point surveys and the perpendicular distance from the line to the original location of the bird was recorded for line transects. To account for birds flushed from locations close to points or lines due to

approaching observers, we recorded the distance to the original locations of those birds, prior to flushing.

Because detectability is influenced by many factors such as observer performance, weather variables, and physical and behavioral characteristics of birds that make them more or less detectable by observers (Rosenstock et al. 2002), we used survey protocols to maximize detectability and recorded environmental covariates to examine their effect. Following ALMS protocols for conducting landbird surveys in the Arctic (Handel and Cady 2004), we began surveys at 0300 (AKDT) and concluded by 0900, and we did not sample when detection of birds was impaired by inclement weather such as rain, snow, wind, and fog. We recorded environmental covariates before starting each 10-minute point count: temperature (°C), Beaufort wind scale (mph: <1, 1-3, 4-7, 8-12, 13-18, and 19-24), sky condition (clear, partly cloudy, cloudy, fog or smoke, drizzle, snow, and showers), and noise (none, slight, and considerable). For each bird detected, we recorded the distance to the bird (using laser range finders if possible), time of detection, and type of detection (e.g. singing, calling, visual). For visual detections, we also recorded sex of the bird. Observers were trained in sampling protocols and oriented to Smith's Longspur vocalizations and behaviors for a week prior to dispersing to study sites to conduct surveys. All data were collected in accordance with federal animal care and research permits (University of Alaska, Fairbanks IACUC #07-19).

Data Analysis

Estimating density. To produce unbiased estimates of density, we designed and conducted our surveys with distance sampling assumptions in mind: 1) survey points and lines were distributed randomly or systematically within study sites; 2) distances were measured accurately; 3) birds were detected at their initial location, prior to any movement in response to the observer; and 4) all birds on or near the point or line were detected. Associated with the fourth assumption is the assumption that all birds present in the survey area sing, call, or behave in some way that can be detected by the observer, referred to as the bird's availability (Farnsworth et al. 2002, Alldredge et al. 2007). To meet the assumption that all birds close to the point or line are detected, standardized methodology is used to control for variation in the availability of birds.

We conducted surveys in June to correspond with the early breeding season when male Smith's Longspurs sing vigorously to attract females (Jehl 1968). Like most passerines, females are less conspicuous than males during the breeding season both in plumage and behavior, and therefore would have lower detectability. Thus, we only used detections of males to model detectability and estimate densities. Due to the open nature of tundra habitat and the conspicuousness of males during the breeding season, we expected little variability in detectability of males across study sites, so we pooled observations from all study sites to achieve the 60-100 observations recommended for modeling detectability with distance sampling (Buckland 2001, Rosenstock et al. 2002). With the pooled observations, we fit detection functions to model the decrease in detectability of birds using MCDS in program DISTANCE, version 6.0 (Thomas et al. 2010). Following standard techniques for distance sampling analysis, we first fit a basic detection function (Buckland 2001, Marques et al. 2007). For our male Smith's Longspurs data, this was achieved by grouping observed distances into 20-m intervals, truncating the data at 140 m, and using the hazard rate key function. Second, we used forward stepwise selection to build detection functions using covariates from point surveys: observer, observer experience (one or more seasons experience yes/no), temperature (°C), Beaufort wind (modeled as both a categorical and continuous variable), sky condition (categorical), precipitation (categorical yes/no), and noise (categorical). Because we did not have covariate data for three sites (Noatak, Killik, and Itkillik) we did not include them in the covariate modeling. We evaluated detection histograms for indication of bias from violations of sampling assumptions such as inadequate numbers of detections close to the line (a common criticism of point surveys for birds), or heaping of observations due to bird behavior or measurement error (Buckland 2001). We selected the top covariate models based on the fit of the detection functions and precision of density estimates (%CV and 95% confidence intervals) and using Bayesian information criterion (BIC, Burnham and Anderson 2004).

Evaluating survey methods. Standardization of survey methods is used to reduce variability in detectability associated with environmental conditions. We used replicates of point and line surveys conducted in Atigun Gorge 2007-2009 to evaluate the timing of surveys as well as the effectiveness of these two common distance-sampling methods for estimating densities of Smith's Longspurs. Point surveys have been known to fail to

properly detect birds close to the point because birds move away upon arrival of observers or birds hide when observers are near (Buckland et al. 2008). Failure to detect birds near the point or line is a violation of an important distance sampling assumption and introduces negative bias into density estimates (Buckland 2001). By design, line surveys do not have this problem because birds on or near the line are detected ahead of the observer and thus are not affected by the presence of the observer at 0 m. Point surveys are more sensitive than line surveys to bias from undetected movement and measurement error, because for point surveys, the surveyed area increases quadratically with distance, whereas for line surveys the surveyed area is equal for all distances (Buckland 1985, Buckland 2001).

In addition, inconspicuous birds can sometimes be missed on surveys, which can lead to negatively biased results especially if the missed birds are close to the point or line. To evaluate this source of bias, we examined how within-season timing and duration of count affected survey results. Bird behavior is known to change throughout the annual cycle with more conspicuous behavior typically associated with attracting mates and maintaining territories during the breeding season. Changes in conspicuousness are not accounted for in distance sampling. Instead, variability is controlled through standardization of survey dates designed to maximize detectability. The duration of count is known to affect the results of point surveys because of its influence on detectability (Lee and Marsden 2008) and in some cases length of count can impact the ability of point surveys to satisfy the assumptions of distance sampling. Longer counts can be advantageous for detecting less conspicuous birds (Fuller and Langslow 1984) and therefore can be important for meeting the assumption that all birds at or near 0 m are detected (Buckland et al. 2008). However, longer counts can result in biased estimates if birds move prior to being detected. Undetected attractive movement of birds into the survey area and closer to the observer can inflate density estimates and likewise, undetected evasive movements can result in reduced density estimates (Lee and Marsden 2008). Longer counts require that observers track birds previously detected to avoid double-counting, which would also inflate density estimates. Much depends of the behavior of the species and visibility afforded by the environment. Choice of count duration, therefore, must balance the need for increased detectability of inconspicuous birds with the risk of introducing bias.

Within-season variability. We examined replicate point and line surveys conducted on three routes in Atigun Gorge 31 May - 24 June 2007-2009 to determine whether there was a relationship between within-season timing of surveys and number of detections on surveys. To account for imperfect detectability at greater distances, we first truncated observations >100 m to calculate counts for the area where detectability was high (based on the results from the analysis of pooled observations). We then plotted the total counts from each route against the day of year each route was surveyed. This suggested a decline in conspicuousness later in the season, which was validated by the decline in the probability of availability for observations before (P_{avail} = 0.92, 95% CI 0.04-1.0) and after 12 June (P_{avail} = 0.85, 95% CI 0.1-1.1), calculated via time removal models with 2.5 minute survey intervals following Farnsworth et al. (2002) (Colleen Handel, USGS Alaska Science Center, personal communication). We attributed the reduction in detections after 12 June to diminished conspicuousness of males after females began incubating eggs. Because reduced availability can negatively bias estimates from distance sampling, we thus only included replicate surveys conducted 1-12 June to estimate density in all of our analyses.

Annual variability. We calculated density estimates for each year using Atigun Gorge point surveys conducted 1-12 June 2007-2009. Observations were pooled to model detectability in program DISTANCE, version 6.0 (Thomas et al. 2010) and density estimates were made by applying the pooled detection function to the observations from each year. The model used to fit the observations pooled from all sites also fit the Atigun Gorge data, and so was used for consistency and comparison: distances were grouped into 20-m intervals, observations were truncated beyond 140 m, and the hazard rate key function was used.

Point and line surveys. To compare the effectiveness of point and line surveys, we compared density estimates generated by each method and evaluated how well the methods met distance-sampling assumptions. For comparison of point and line surveys, we built basic detection functions using only the data from the surveys where points and lines were conducted simultaneously at Atigun Gorge 2007 and 2009; because we did not conduct line surveys in 2008, the point surveys conducted that year were excluded from the point survey estimates. We evaluated count histograms for indication of

sampling bias and examined the variance (%) and 95% confidence interval to assess the precision of the density estimates.

We calculated density using observations recorded within 2.5 min, 5 min, 7.5 min, and 10 min survey periods to examine the affect on density estimates and to evaluate method assumptions. Using program DISTANCE, version 6.0 (Thomas et al. 2010) to calculate density, we fit models for each duration of count by grouping observed distances into 20-m intervals, truncating the data at 140 m, and using the hazard rate key function.

Estimating population. As a measure of abundance, density estimates are useful because they can be used to estimate population size when coupled with area of occurrence. While we acknowledge that our surveys were not originally designed to estimate population size, we recognized the opportunity to use our density estimates to estimate the population of Smith's Longspurs by applying densities to the area of predicted occurrence derived from our previous work. Using habitat characteristics, we predicted areas of high suitability (probability of occurrence >0.45) for Smiths Longspurs in the Brooks Range (Chapter 1). We then derived population estimates using the average, highest, and lowest density estimates for the area of high predicted occurrence in the eastern ecoregion within the known breeding range of Smith's Longspurs (Fig. 2.2) and in the entire Brooks Range ecoregion. We generated these two estimates because we had the most confidence in the accuracy of our occurrence model for the eastern Brooks Range; the entire ecoregion included areas in the west where predicted occurrence was less certain due to limited survey coverage. We used the average, highest, and lowest density estimates because of the high spatial variability in densities at the local scale and to suggest possible bounds of the population estimates. We understand the uncertainty surrounding the predicted area of occurrence related to limitations of the species distribution model (i.e. accuracy, scale); however, our aim was to provide better estimates of the numbers of breeding Smith's Longspur possible in northern Alaska.

RESULTS

We detected 10 915 birds and 82 species on 88 point-survey routes at nine sites (Appendix 2.1). The most common species detected on all surveys were American Tree Sparrow (*Spizella arborea*, n = 1569), White-crowned Sparrow (*Zonotrichia leucophrys*; n = 1158), and Savannah Sparrow (*Passerculus sandwichensis*; n = 1063), followed by Smith's Longspur (n = 571), Lapland Longspur (*Calcarius lapponicus*, n = 552), Common Redpoll (*Acanthis flammea*, n = 502), and American Robin (*Turdus migratorius*, n = 430). We detected Smith's Longspurs on surveys at seven of the nine sites (Table 2.2); they were not detected on Killik or Coleen surveys, but a few individuals were detected within the Coleen River study area.

Density estimates. Although several sites had only a few detections of males and several routes had no detections, sufficient numbers for distance sampling analysis were achieved by pooling the detections from all sites. After truncating data and removing observations of females and birds with unidentified sex, we generated density estimates using 327 observations of male Smith's Longspur. Based on lowest BIC and the fit of MCDS detection functions, our top model included no covariates. All other covariates reduced the fit of the detection function, added variance to the estimates, and had BIC >2 above the top model. Density estimates were generally low (Table 2.2), and varied among sites with the highest densities in the northern sites (Atigun, Canning, and Sunset Pass) and lowest in the westernmost site (Noatak). Precision was lowest for the two sites with the highest densities and confidence intervals were large (Table 2.2).

Within-season variability. At Atigun Gorge, the total detections of males per route from point surveys and line surveys declined as the breeding season progressed; particularly after the onset of incubation (Fig. 2.3).

Annual variability. Density estimates derived from replicate point surveys conducted at Atigun Gorge, 1-12 June 2007-2009, showed little annual variability. Densities ranged from 0.23 males/ha (95% CI = 0.05-1.2 males/ha, CV = 46%) in 2007, to 0.28 males/ha (95% CI = 0.02-3.3 males/ha, CV = 68%) in 2008 and (95% CI = 0.03-2.2 males/ha, CV = 58%) in 2009.

Point and line surveys. To evaluate the effectiveness of point and line survey methods, we used observations from replicate point and line surveys at Atigun Gorge (point surveys n = 87 males; line surveys n = 126 males). The basic distance sampling detection function for both point and line surveys had broad shoulders and similar effective distances (point survey EDR = 112 m, 95% CI = 95-132 m; line survey EDW = 118 m, 95% CI = 101-137 m). The count histogram for point surveys indicated we detected more birds than expected in the closest intervals (Fig. 2.4a), whereas for line surveys, we detected fewer than expected at closer intervals (0-40 m) and more than expected at 40-80 m (Fig. 2.4b). The larger area surveyed by line surveys detected more birds, but density estimates derived from line surveys (0.12 males/ha, 95% CI = 0.08-0.17 males/ha, CV = 15%) were half those derived from the point surveys (0.24 males/ha, 95% CI = 0.09-0.67, CV = 40%), with slightly overlapping confidence intervals.

For point count surveys, the majority of detections occurred at the beginning of the 10-minute count (Table 2.3). Of detections used for estimating density, 62% occurred in the first 2.5-minute period, 11% occurred in each of the two middle time periods, and 15% occurred in the last 2.5-minute period. Overall, the 10-minute count produced a density estimate that was 25% higher than the estimate generated by a 2.5-minute count and was 10% higher than the 5- and 7.5-minute counts. Increases were slight and confidence intervals overlapped (Table 2.3). When we examined the timing of observations across sighting distances, we found both near and far detections scattered across the duration of the 10-minute count.

Population estimates. Using the mean, lowest, and highest density estimates applied to the area of high predicted occurrence, we estimated approximately 30 000 males in the eastern Brooks Range where Smith's Longspur are currently known to occur (Table 2.4). If the species also occurs in similar density in the western part of the Brooks Range where we have predicted high probability of occurrence, there could be approximately 50 000 males across the ecoregion, with no more than 160 000 males likely.

DISCUSSION

Smith's Longspurs were uncommon across much of the Brooks Range ecoregion because occurrence is limited by unsuitable habitat in large forested valleys and rugged mountains. However, they were locally abundant in various moist sedge-shrub tundra habitats in broad tundra valleys and low-mountain slopes of the Brooks Range ecoregion (Chapter 1, Gotthardt and Jansen 2004). Among the seven sites where Smith's Longspurs were found, the highest densities were at two of the northern sites, Atigun and Canning. We expect Smith's Longspur may occur at similar densities in other sites across the northeastern edge of the ecoregion where they are also thought to be present (Chapter 1). Farther south, on the southeastern edge of the ecoregion, Smith's Longspurs were uncommon and densities were low, most likely due to the patchiness of suitable habitat within the tundra-forest transition zone (Jehl 1968). The species was also uncommon, but locally abundant on a few routes within the westernmost study site (Noatak); overall this area had low a density of breeding birds. Noatak is at the westernmost edge of the species' known breeding range. Farther west, our model predicted Smith's Longspurs would occur in upland habitats in the broad valleys and passes of the western Brooks Range (Chapter 1). This is an area that needs more exploration to determine abundance of Smith's Longspurs in the west.

We found that distance sampling point surveys were an effective means of estimating abundance of male Smith's Longspur. The species was uncommon within many sites, resulting in few detections, but by pooling observations from all sites we successfully fitted a detection model for estimating densities for each site. We found no evidence that the assumptions of distance sampling were violated on point surveys, largely due to the conspicuousness of male Smith's Longspurs while attracting mates and the visibility provided by the open habitats in which they breed. Observer training and the use of laser range finders were also important for accuracy (Pendleton 1995, Ransom and Pinchak 2003). Differences among observers can have an effect on detections (Sauer et al. 1994, Kendall et al. 1996), even in open landscapes (Diefenbach, 2007), yet we did not find a significant effect from individual observers or observers grouped by experience. Detectability was not significantly affected by noise,

wind, sky condition, or precipitation covariates, indicating that we applied appropriate cut-offs for surveying (Marques et al. 2007).

A fundamental consideration for distance sampling surveys is the timing of surveys. The rate at which birds sing is known to vary throughout the breeding season (Slagsvold 1977, Best 1981, Wilson and Bart 1985, McShea and Rappole 1997), with singing generally declining after territories have been established and incubation commences. Because bird surveys rely largely on aural cues to detect individuals, it is important to conduct surveys when birds are more detectable. We found within-season timing of surveys for Smith's Longspurs to be important for deriving the best estimates of abundance and density. From repeated surveys at Atigun Gorge, we found that detections declined from late May through June. Based on concurrent nest monitoring in Atigun Gorge in 2007-2009, we found that average onset of incubation was 12 June (Wild, unpublished data), which coincided with the decline in detections on survey routes. Based on these results, we excluded surveys conducted after 12 June to estimate density for Atigun Gorge. However, we do not know how the seasonal decrease in availability affected survey results at other sites, but suspect surveys conducted later in June could be biased low for the same reason. In particular, because of logistics, some of the Itkillik, Killik, and Coleen surveys were conducted in late June and may have detected fewer birds if nest initiation and incubation had already started at these sites.

At Atigun Gorge, we found little variability in densities among years. We attribute the lack of variability to the species' high fidelity to breeding sites documented by color-marked birds in Canada (Jehl 2004) and in Alaska (Wild, unpublished data). In some areas, however, the species may be more nomadic, as was suspected in a nesting study at one site in Manitoba, Canada where numbers varied widely in the late 1990s (Briskie 2009). In northern Alaska, the Breeding Bird Survey (BBS) Happy Valley route, approximately 100 km north of the Atigun Gorge study site, has routinely detected Smith's Longspur since 1995 (www.pwrc.usgs.gov/BBS/). Numbers detected each year on the Happy Valley route varied widely from 0-17 Smith's Longspur detected. Causes of the annual variability on this route have not been explored, but the annual variability could indicate nomadic behavior. However, these surveys were conducted annually

between 16-25 June, and the later timing of the surveys may produce unreliable and variable results. Understanding that these studies are not directly comparable due to their different scope and methods, they may indicate site specific differences in site fidelity and environmental conditions upon arrival in the spring. This highlights the importance of long-term studies on the species' breeding ecology across their range.

Survey methodology is also a fundamental consideration for study design that can influence survey results. Because we had no measure of "true" density with which to compare our estimates, we compared point and line survey results and explored common assumption violations for each method. We made a fair comparison of the methods by simultaneously conducting point and line surveys following standardized protocols with distance sampling assumptions in mind. Point and line surveys resulted in different density estimates, with line surveys resulting in density estimates approximately half of those derived from points. Confidence intervals overlapped suggesting that the estimates are not significantly different and "true" density is likely within that range. However, differences in the density estimates generated by point and line surveys suggested that distance sampling assumptions were somehow violated (Buckland 2001).

The most common violations in bird surveys are from double counting, measurement error, undetected movement, or failure to detect birds near the point or line (Buckland et al. 2008). Due to the open habitats in which we surveyed, it was possible to locate and track individuals, thereby reducing the chance of double counting and improving the accuracy of measurements. Count histograms showed some indication of undetected movement for both point and line surveys. When we examined the duration of count, we found ≥10-minute survey periods are needed to meet the assumption that all birds on or close to the point were detected. This finding has implications for line surveys, suggesting that estimates derived from them may be biased low because less conspicuous birds were not detected while walking through the area. This could be ameliorated by walking at a slower pace, but it remains to be explored in future studies.

We produced the first density estimates of Smith's Longspurs in Alaska and used this information to estimate there to be approximately 30 000 males in the eastern

Brooks Range with as many as 50 000 males possible across the range. These estimates suggest the total population may be larger than previously thought. However, uncertainty still surrounds our estimates due to patchy distribution and variable densities, which likely exist across the entire breeding range of the species. We found that Smith's Longspurs were patchily distributed both locally and on a broad landscape level, which is likely due to the limited distribution of suitable habitat across the landscape (Chapter 1). Although we found that densities were similar among three years at Atigun Gorge, large fluctuations in the number of breeding birds near Churchill, Manitoba from 1995-2000 (Jehl 2004) suggests variation in local population size may occur. The causes of these fluctuations are unknown, and highlight the importance of long-term monitoring of population size and reproductive success. In addition, our previous work also indicated that potentially suitable habitat may not have been occupied (Chapter 1). Reasons for this are unknown, but should be explored more fully to understand patterns of local and landscape occupancy (MacKenzie et al. 2002) and reduce uncertainty surrounding abundance estimates.

Reliable estimates of density are critical for identifying important geographic areas and habitats for the species in addition to tracking change and setting conservation priorities. We addressed considerations for designing effective surveys for Smith's Longspurs. Based on this study, commonly used point survey methods appeared to meet distance sampling assumptions better than line surveys for estimating density; however, refinement of line surveys should be explored. A monitoring program for Smith's Longspur should be designed to also investigate other important factors for understanding the species breeding ecology such as differences in abundance associated with shrub tundra communities and shrub growth as well as the effect of seasonal weather patterns and phenology. This information is increasingly important due forecasted effects of climate change in the arctic.

With climate change, many birds are migrating and nesting earlier in spring, and we need to understand and monitor seasonal changes in behavior to understand how these changes may affect abundance surveys (McClure et al. 2011). A monitoring program designed to target Smith's Longspurs would also capture a unique community of birds

found in the ecotone between tundra and boreal forest (Appendix 2.1) and will be useful for monitoring changes in distribution and abundance in a changing environment.

ACKNOWLEDGEMENTS

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Fig. 2.1 Location of nine study sites used to estimate density of Smith's Longspur in the Brooks Range, Alaska. Sites, surveyed in June 2003-2009, are scattered across the transition from boreal forest habitats (green areas) in the south to the sedge and shrub tundra habitats (brown areas). Much of this area is managed by the National Park Service and U.S. Fish & Wildlife Service (yellow boundaries) with responsibility for conservation of wildlife and their habitats.

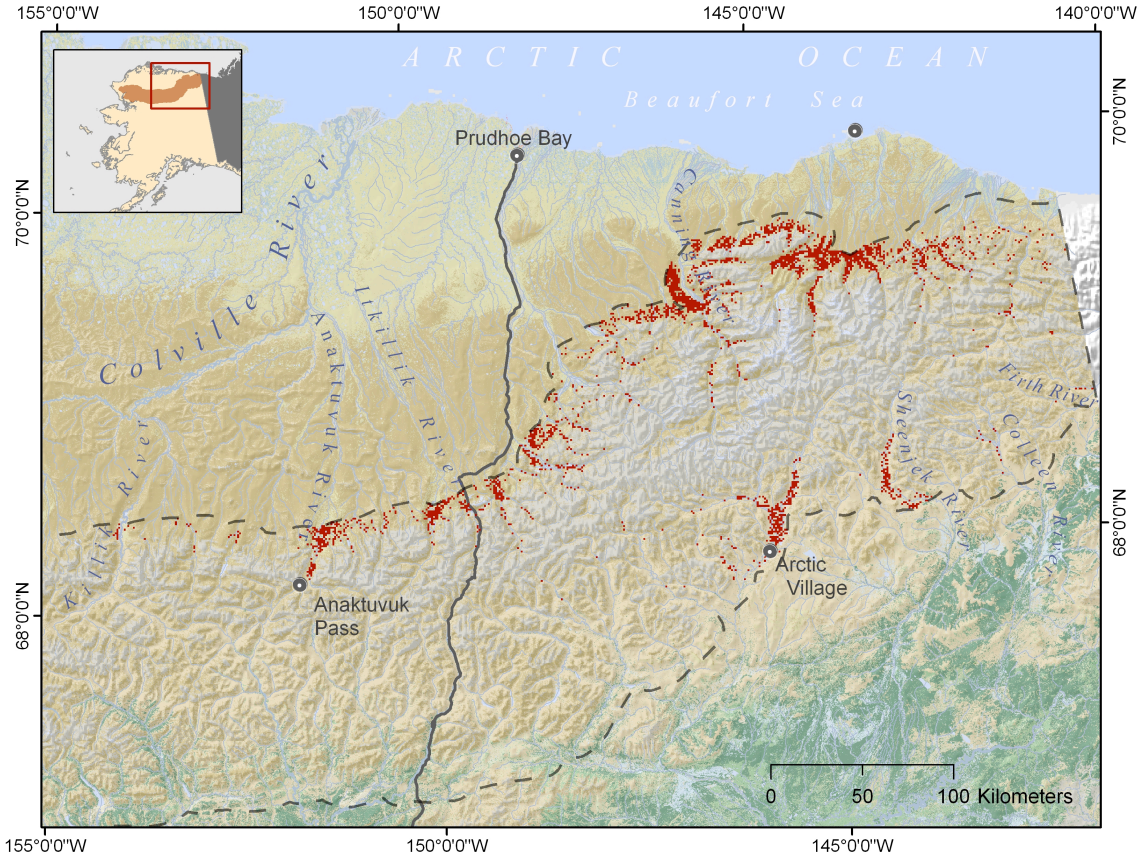

Figure 2.2 Eastern area of high predicted occurrence for Smith's Longspur, shown in red (251 500 ha), used to estimate numbers of males in the eastern Brooks Range, Alaska from surveys conducted at nine sites during June 2003-2009.

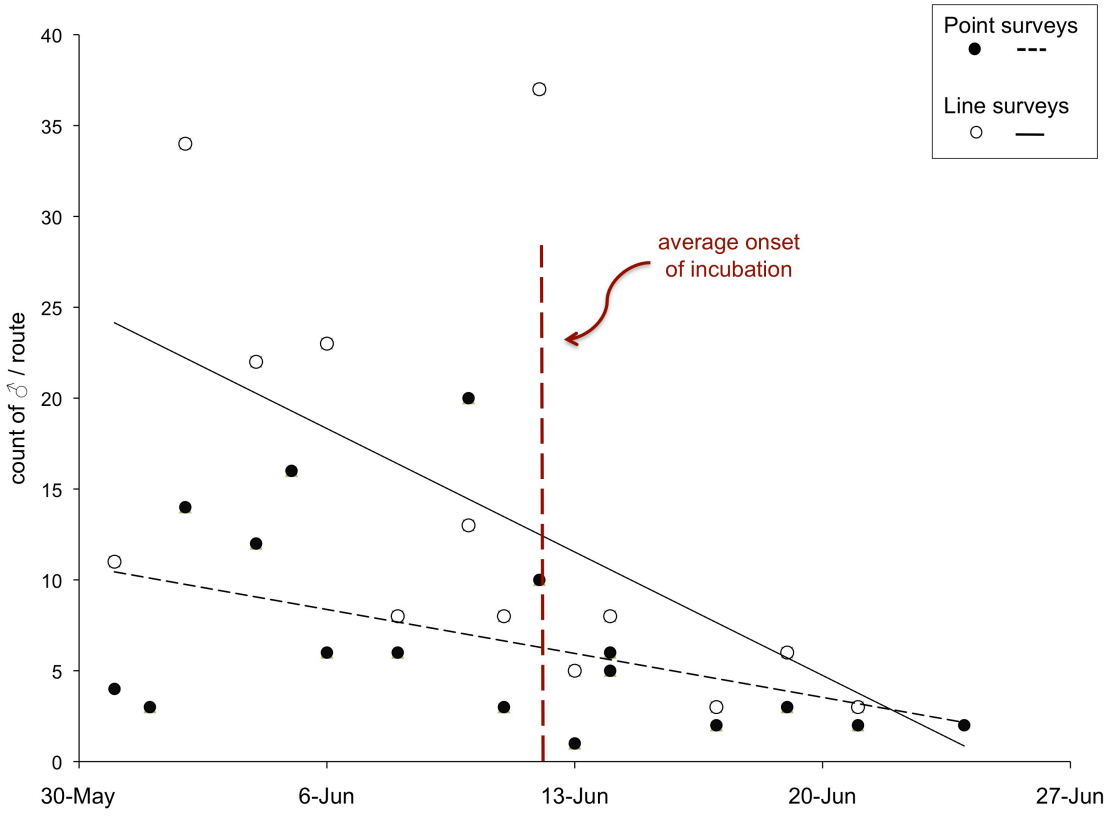

Fig. 2.3 Decline in detection of Smith's Longspur males by date on replicates of three routes surveyed at Atigun Gorge, Alaska, May 31-June 24 2007-2009. The red line at 12 June indicates the average onset of incubation for Smith's Longspur nesting in Atigun Gorge during the same period.

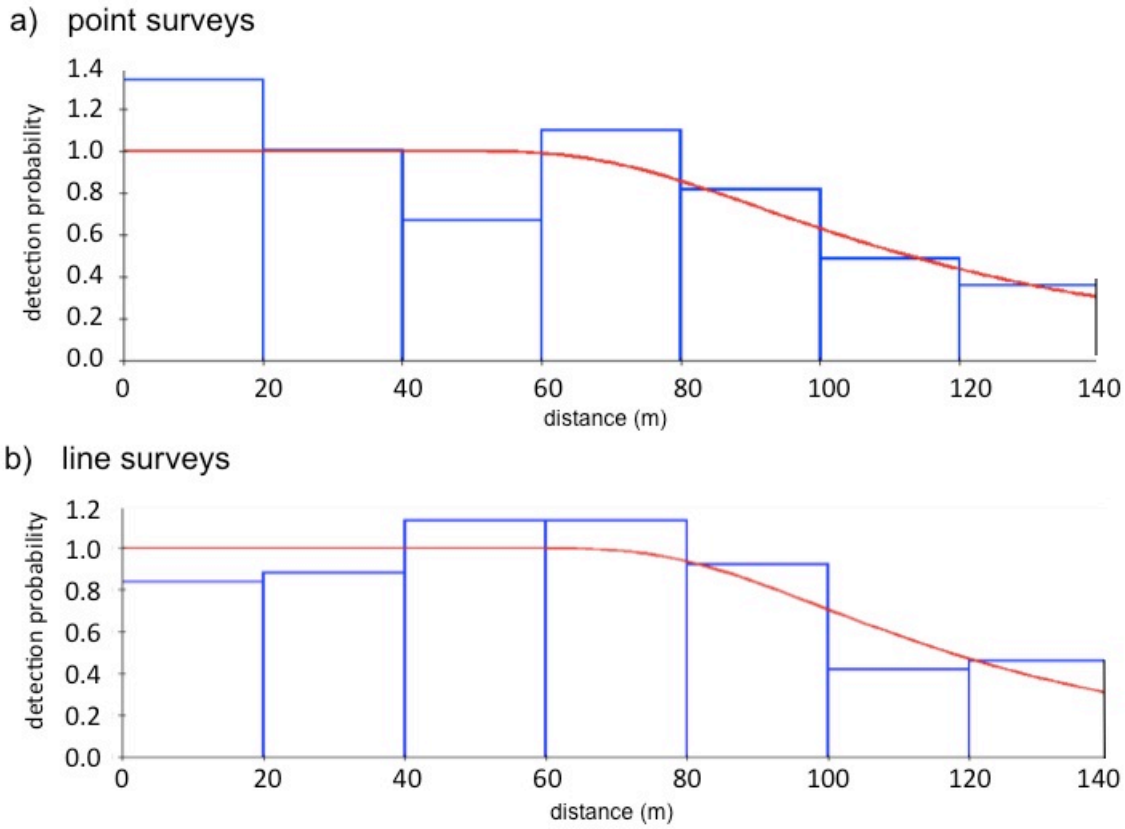

Figure 2.4 Detection function (red line) and histogram (blue bars) of observations of male Smith's Longspur from three pooled replicate point (a) and line (b) surveys conducted simultaneously at Atigun Gorge, Alaska in June 2007 and 2009. Observations were modeled with the hazard rate key function with 20-m distance intervals, and truncation of observations at 140 m.

Table 2.1 Location, dates, and descriptions of nine sites surveyed for Smith's Longspur in the Brooks Range, Alaska, 2003-2009

site	survey dates	no. routes (points) surveyed	starting coordinates	ending coordinates	elevation (m)[a]	habitat
Noatak	10 - 26 June, 2004 8 - 21 June, 2008	15 (177) 9 (49)	67.59614 -155.23120	67.85827 -156.35297	539 ± 28	tundra
Killik	19 - 27 June, 2003	10 (72)	68.15116 -154.16810	68.36087 -153.99628	550 ± 27	tundra
Itkillik	17 - 26 June, 2005 14 - 23 June, 2006	9 (102) 9 (63)	68.25089 -149.99295	68.43347 -149.90913	700 ± 33	tundra
Atigun Gorge	31 May - 21 June, 2007 31 May - 24 June, 2008 2 - 16 June, 2009	3 (98) 3 (66) 3 (47)	68.467598 -149.293126	68.478454 -149.162491	925 ± 104	tundra
Canning	6 - 16 June, 2009	5 (40)	69.34383 -146.09614	69.39679 -146.15774	380 ± 58	tundra
Sunset Pass	3 - 10 June, 2006	5 (50)	69.65898 -144.72961	69.58110 -144.77275	564 ± 84	tundra
Sheenjek	8 - 21 June, 2008	8 (80)	68.71628 -143.82663	68.43403 -143.90330	691 ± 30	tundra/forest
Coleen	17 - 19 June, 2009	3 (30)	68.62161 -142.45140	68.65613 -142.45000	628 ± 185	tundra/forest
Firth	5 - 17 June, 2008	6 (60)	68.66156 -141.09158	68.73829 -141.33619	583 ± 43	tundra/forest

[a] Mean ± SD elevation of points surveyed

Table 2.2: Survey results and density estimates for male Smith's Longspur from distance sampling point surveys conducted at nine sites across the Brooks Range, Alaska during June 2003-2009.

site	routes (%) with Smith's Longspur	points (%) with Smith's Longspur	detections of ♂s	density (♂/ha)	95% confidence interval	coefficient of variation
Brooks Range[a]	64%	33%	385	0.13	-	-
Noatak (2004, 2008)	53%, 75%	12%, 33%	21, 28	0.04	0.03 - 0.05	7%
Killik	0%	0%	0	0	-	-
Itkillik (2005, 2006)	78%, 89%	23%, 52%	26, 53	0.16	0.13 - 0.2	10%
Atigun (2007, 2008, 2009)[b]	100%, 100%, 100%,	76%, 74%, 77%	53, 40, 36	0.25	0.06 - 1.08	37%
Canning River	100%,	63%	50	0.41	0.09 - 1.89	52%
Sunset Pass	80%	45%	28	0.19	0.12 - 0.29	18%
Sheenjek River	63%	35%	16	0.08	0.06 - 0.09	9%
Coleen	0%	0%	0	0	-	-
Firth River	67%	31%	9	0.05	0.04 - 0.60	11%

[a]All sites pooled.

[b] Multiple replicates each year from Atigun surveys. Numbers here reflect surveys conducted on or before June 12

Table 2.3 Detections and density estimates for Smith's Longspurs derived from point surveys conducted at Atigun Gorge, June 2007-2009.

count duration	# detections	effective distance radius (m)	density (males/ha)	95% confidence interval	coefficient of variation
2.5 min	54	100	0.16	0.90-0.28	28%
5 min	64	102	0.18	0.10-0.33	30%
7.5 min	74	110	0.18	0.11-0.30	23%
10 min	87	113	0.20	0.12-0.33	23%

Table 2.4 Population estimates for male Smith's Longspur at mean, lowest, and highest density levels (♂s / ha) for the areas of high predicted occurrence in the eastern Brooks Range, Alaska within the species known breeding range and in the entire Brooks Range ecoregion.

predicted occurrence area	mean density 0.13 (♂s / ha)	lowest density 0.04 (♂s / ha)	highest density 0.41 (♂s / ha)
Eastern Brooks Range (251 500 ha)	32 695	10 060	103 115
Brooks Range Ecoregion (396 100 ha)	51 493	15 844	162 401

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Appendix 2.1 Number of birds and species detected on point surveys conducted for Smith's Longspurs during June 2003-2009 at nine sites in the Brooks Range, Alaska.

	Noatak		Killik	Itkillik		Atigun Gorge			Canning	Sunset Pass	Sheenjek	Coleen	Firth
species name	2004	2008	2003	2005	2006	2007	2008	2009	2009	2006	2008	2009	2008
Canada Goose, *Branta canadensis*							1					5	
Tundra Swan, *Cygnus columbianus*		2	5	1	4	4	8				1		
American Wigeon, *Anas americana*	2						1				3		1
Mallard, *Anas platyrhynchos*	1			1					2		1		1
Northern Shoveler, *Anas clypeata*	14										1		
Northern Pintail, *Anas acuta*													1
Green-winged Teal, *Anas crecca*	2				1								
Greater Scaup, *Aythya marila*	28								1		4		

Appendix 2.1 continued…

Lesser Scaup, *Aythya affinis*											1	2		
Surf Scoter, *Melanitta perspicillata*					1						1			
White-winged Scoter, *Melanitta fusca*	8		4	72	2						5			
Long-tailed Duck, *Clangula hyemalis*	12	2	7	3	6				1		4			
Barrow's Goldeneye, *Bucephala islandica*	2													
Willow Ptarmigan, *Lagopus lagopus*		16	1		9					1	12	3	1	
Rock Ptarmigan, *Lagopus muta*		1	1		2	20	23	14	6	20		2	3	
Red-throated Loon, *Gavia stellata*	1			3										
Pacific Loon, *Gavia pacifica*	5		2		20	4					2			

Appendix 2.1 continued…

| | | |

Appendix 2.1 continued…

Wandering Tattler, *Tringa incana*		11			2	3	3						
Lesser Yellowlegs, *Tringa flavipes*	91	12	31	13	11			1			51	5	2
Upland Sandpiper, *Bartramia longicauda*	56	25	3	6	9	5	3		6		11	3	9
Whimbrel, *Numenius phaeopus*	1											2	3
Bar-tailed Godwit, *Limosa lapponica*													
Semipalmated Sandpiper, *Calidris pusilla*		1			2								
Least Sandpiper, *Calidris minutilla*	6	7	1	30	11				1		4	2	3
Baird's Sandpiper, *Calidris bairdii*							6	3	2				1
Wilson's Snipe, *Gallinago delicata*	27	22	22			4	4	1		2	35	13	5

Appendix 2.1 continued…

Red-necked Phalarope, *Phalaropus lobatus*	7		2	1			1							
Bonaparte's Gull, *Chroicocephalus philadelphia*	3										1			
Mew Gull, *Larus canus*	8	2	1	3	1	1	1					4		
Glaucus Gull, *Larus hyperboreus*			3	1										
Arctic Tern, *Sterna paradisaea*	8		2	21	24									
Pomarine Jaeger, *Stercorarius pomarinus*										2				
Long-tailed Jaeger, *Stercorarius longicaudus*				7	16			2	3	8				
Short-eared Owl, *Asio flammeus*		1								1	2	2	4	
Alder Flycatcher, *Empidonax alnorum*	11						1				4		1	

Appendix 2.1 continued…

Say's Phoebe, *Sayornis saya*						4	5	4					2
Northern Shrike, *Lanius excubitor*			1	1					1		1		
Gray Jay, *Perisoreus canadensis*											7	9	7
Common Raven, *Corvus corax*	2	2		1	2	5	6	4				2	
Horned Lark, *Eremophila alpestris*				5	15	14	8	9	2	6			
Violet-green Swallow, *Tachycineta thalassina*											1		
Bank Swallow, *Riparia riparia*		2									5		
Boreal Chickadee, *Poecile hudsonica*											1		
Ruby-crowned Kinglet, *Regulus calendula*											2		8

Appendix 2.1 continued…

Arctic Warbler, *Phylloscopus borealis*	6	5							2				
Bluethroat, *Luscinia svecica*					3					2			
Northern Wheatear, *Oenanthe oenanthe*						1	2						
Gray-cheeked Thrush, *Catharus minimus*	31		3		4				1		9	1	13
Swainson's Thrush, *Catharus ustulatus*		17										3	
American Robin, *Turdus migratorius*	50	25	27	7	14	88	25	31	17		88	26	32
Varied Thrush, *Ixoreus naevius*											1		4
American Pipit, *Anthus rubescens*	2		1	5	7	91	45	38	1	19	1	1	
Bohemian Waxwing, *Bombycilla garrulus*											2		

Appendix 2.1 continued…

Lapland Longspur, *Calcarius lapponicus*			4	187	193	49	45	44	14	16			
Smith's Longspur, *Calcarius pictus*	34	35		38	87	90	70	67	62	34	38		16
Northern Waterthrush, *Parkesia noveboracensis*					1							1	
Orange-crowned Warbler, *Oreothlypis celata*	65		12	2	3							1	5
Yellow Warbler, *Setophaga petechia*				4					1			3	4
Blackpoll Warbler, *Setophaga striata*	1											1	
Yellow-rumped Warbler, *Setophaga coronata*								1			61		11
Wilson's Warbler, *Cardellina pusilla*			1	1	2		2			1		3	12
American Tree Sparrow, *Spizella arborea*	323	117	188	108	228	93	68	58	46	26	124	75	115

Appendix 2.1 continued…

Savannah Sparrow, *Passerculus sandwichensis*	171	45	101	114	94	46	41	56	54	68	84	37	152
Fox Sparrow, *Passerella iliaca*	5	1	2	1					3		3	49	31
Lincoln's Sparrow, *Melospiza lincolnii*	1											2	
White-crowned Sparrow, *Zonotrichia leucophrys*	252	74	107	75	109	84	60	63	47	29	142	52	64
Golden-crowned Sparrow, *Zonotrichia atricapilla*													4
Dark-eyed Junco, *Junco hyemalis*					1						14		3
Rusty Blackbird, *Euphagus carolinus*											10		
Gray-crowned Rosy-Finch, *Leucosticte tephrocotis*	2					1	1						
Common Redpoll, *Acanthis flammea*	102		162	160	61				9		8		

Appendix 2.1 continued…

Hoary Redpoll, *Acanthis hornemanni*								1					
Redpoll, *Acanthis spp.*		44				2	6	26		6	24	3	5
Grand Total	1365	479	702	944	1006	613	435	423	288	244	774	317	523

GENERAL CONCLUSIONS

This thesis addressed critical information needs for the conservation of Smith's Longspur, a species of concern in North America. Prior to this study, we had only a limited understanding of the breeding distribution and abundance of the species, largely due to poor coverage by monitoring programs in their remote arctic and subarctic breeding grounds. I located several breeding areas within seven sites on surveys conducted at 12 sites across the western part of the breeding range over a span of seven years, 2003-2009. I described local and landscape level habitat associations with a mosaic of sedge-shrub habitats primarily composed of moss and sedges with limited cover of dwarf and erect shrubs. Occurrence information was used to create a predicted distribution map for the ecoregion that reflected a patchy distribution associated with broad valleys and foothills in the east and upland plateaus in west. Bird surveys were used to estimate density for each site and estimated abundance across a broad geographical area, the Brooks Range, Alaska.

Across the ecoregion, the highest densities of Smith's Longspur were found in the eastern part of the study area, within broad valleys along the northern front of the mountains. This northeastern edge of the Brooks Range ecoregion (Nowacki et al. 2001) likely supports the largest numbers of Smith's Longspurs in the ecoregion because there are large areas of predicted occurrence in the area where we estimated the highest densities. In other parts of the ecoregion, few birds were detected on surveys, predicted distribution was patchy, and density was lower, therefore numbers in other parts of the Brooks Range are expected to be small. This includes areas such as the mountain valleys, along the southeastern edge of the study area within the tundra-transition zone. Numbers are also likely to be low in the west. Smith's Longspurs were found in low density along the upper reaches of the Noatak River. Farther west, beyond the western edge of their presumed breeding range, numbers are uncertain, but the region may support thousands of Smith's Longspurs, as many upland plateaus are predicted to be suitable for the species. Uncertainty is higher for these western-most predictions because few surveys have been conducted prior to my work in the western Brooks Range; more targeted surveys are needed there to document breeding and to fine-tune the predictive model.

The predictive distribution map for Smith's Longspur in the Brooks Range is an important tool for conservation that will help resource managers locate more breeding areas and further explore patterns of distribution and abundance. I used the area of high predicted occurrence predicted by my distribution model to calculate the first population estimate for Smith's Longspur in the Brooks Range. My estimations determined that as many as 50,000 males may occupy this region, but 10,000-30,000 males are more likely based on the species' patchy distribution, variable density, and inaccuracies in the predicted distribution. These estimates question the current total population estimate of >75,000 birds; the high numbers in northern Alaska suggest that the total population may be much higher than previously thought. Much is still unknown about the distribution and abundance of the species across other parts of their breeding range in Alaska and Canada.

Estimates of total population size for the species are likely to remain uncertain due to variability in density and patchy distribution, but we can effectively monitor trends in distribution and abundance to inform conservation efforts. I found that distance-sampling point surveys were effective for surveying abundance of Smith's Longspurs using standard multi-species survey protocols used by the Alaska Landbird Monitoring surveys (Handel and Cady 2004). I examined replicate surveys conducted for three years (2007-2009) and made recommendations for surveying breeding Smith's Longspurs: conduct surveys prior to the onset of incubation ≥12 June, conduct point counts for ≥10 minutes, use laser range finders, provide observers with training, and follow Alaska Landbird Monitoring Survey protocols for distance sampling. Surveys targeting Smith's Longspur are also likely to effectively study the patterns of abundance and habitat relationships of other landbirds.

In addition to refining survey methods, my data on habitat associations of Smith's Longspurs (sedge tundra, dwarf shrub tundra, and open shrub tundra) may assist in the development of stratified sampling schemes to focus survey efforts on locations that are suitable for the species. A monitoring program can also be designed to examine differences in abundance between habitat types, assess the effect of seasonal weather patterns such as patterns of snowmelt and storm events, and monitor changes in vegetation and climate. This information is especially important because of

the large impacts of climate change forecasted for the Smith's Longspur's breeding range.

The arctic region in northern Alaska has been warming faster than other parts of the world for over three decades (Serreze et al. 2000). Environmental responses to this warming have already been documented and include reduced snow cover duration and extent (Stone et al. 2002, Euskirchen et al. 2009) and lengthening of the growing season (Myneni et al. 1997, Smith et al. 2004). In the Arctic, shrubs are expected to grow larger and more dense (Tape et al. 2006), especially alder (*Alnus* spp.; Tape et al. 2006) and dwarf birch (*Betula* spp.; Euskirchen 2009), while at the same time moss and lichen cover decrease (Chapin et al. 1995, Hobbie and Chapin 1998, Hinzman et al. 2005). Greater uncertainty surrounds forecasts for tree growth and advance in tree line, due to concerns about temperature-induced drought stress (Barber et al. 2000, Wilmking et al. 2004) and the role of the rugged mountains of the Brooks Range as a barrier to dispersal of plant species (Rupp et al. 2001). Higher evaporation rates are expected to lead to drier soils and shrinking wetlands (Euskirchen 2009). Based on this study, increased shrub cover and reduced moss cover are likely to reduce Smith's Longspur habitat quality and limit their distribution in the Brooks Range to wetland patches and alpine tundra plateaus where moist sedge-shrub habitat may persist. Conversely, expected expansion of shrubs farther north may create suitable habitat, thus supporting a northward distribution shift.

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